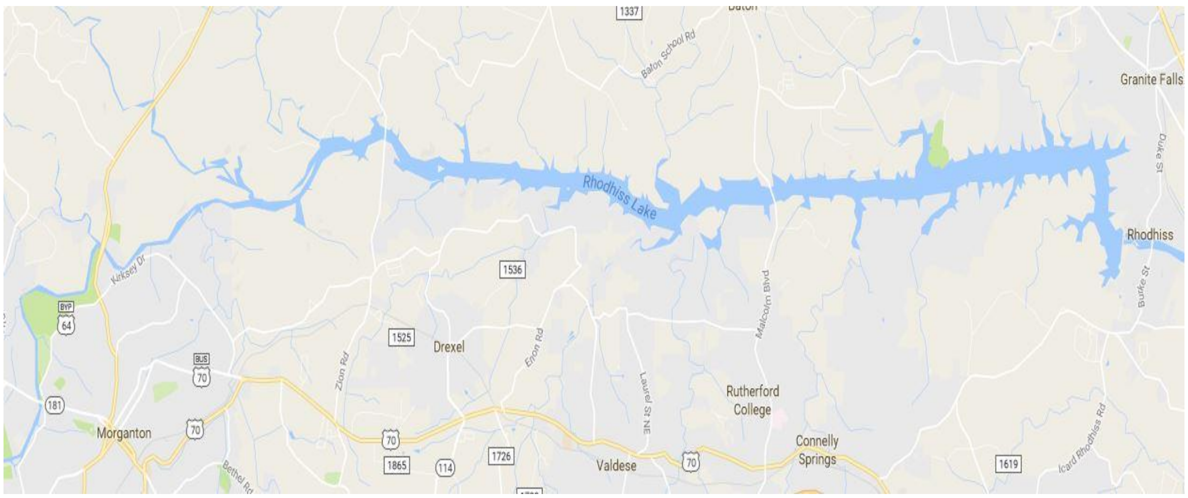
1973-2014 Historical Review of the Water Quality of Rhodhiss Lake, North Carolina, with Emphasis on Nutrient Loading and Export



Prepared

February, 2017

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Acknowledgements

This project was funded by the Catawba-Wateree Water Management Group, Duke Energy and the City of Hickory and managed by Carolina Land and Lakes, RC&D.

Water quality data collected prior to 2004 by Duke Energy, NCDENR, and the USGS were originally compiled and formatted by Mary Rodriguez as part of the Catawba-Wateree Project, FERC License #2232. Water quality data collected in 2004 by Duke Energy for the re-licensing project was also included. Historical hydrological data was calculated using water balance spreadsheets originally developed by Duke for the CHEOPS re-licensing model. The water balance calculations were continued to include recent operational data supplied by Duke Energy-Hydro Operations.

Historical (prior to 2004) and recent (2005-2014) NCDENR lake assessment water quality data were supplied by Debra Owen, NCDNR. Water quality data collected by the United States Geological Survey (USGS), 1993-1994, was provided by Mary J Giorgino.

Rhodhiss tailrace was sampled twice per month (2010-2014) by the City of Hickory, Assistant Public Services, Kevin B. Greer, Director-Public Utilities. Duke Energy transported the samples and provided laboratory analysis, which was sponsored by Duke's Water Strategy, Hydro Licensing and Lake Services. Jay Perkins, Duke Energy Analytical Laboratory, provided the chemical and quality control results.

Thanks are also due to John Derwort, Duke Energy, Water Resources, for providing the phytoplankton count data.

The author made no attempt to adjust inter-laboratory results relative to reporting limits, detection limits, or data base inclusions. Since each laboratory was responsible for its own quality control, all laboratory values were used as the data bases were provided.

The careful and thoughtful reviews and suggestions made by Jack Huss and Kevin Greer greatly added to the relevance of the report.

Finally, the vision and persistence of Jack Huss by obtaining the funding and coordinating activities of the various groups, and especially the gentle prodding to the author, made this report possible.

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1. INTRODUCTION

The North Carolina Division of Water Quality (NCDWQ) has conducted water quality sampling on Lake Rhodhiss at three to five year intervals since the early 1980's. In 2000, NCDWQ classified this reservoir as mesotrophic and fully supporting all drinking water supply, aquatic life, and primary and secondary recreational uses, with no fish advisories. During the 1999-2002 low flow years, both Valdese and Lenoir experienced taste and odor problems in their potable water supply and NCDWQ reported high dissolved oxygen above saturation levels, high pH and high chlorophyll levels. However, by 2004, with six of seven water quality parameters identified as lake stressors (percent saturation DO, algae, chlorophyll a, pH, sediment, and taste and odor), NCDWQ reported that Rhodhiss Lake suffers from eutrophication and was impaired in its support of aquatic life. In 2008, the North Carolina 303(d) list was updated to include Rhodhiss Lake for exhibiting high pH values.

During the period 2005 – 2008, Carolina Land and Lakes RC&D received and administered a 319 non-point source grant from NCDWQ. The federal portion of the project had matching from local government, NC agriculture cost share funds, and a grant from Duke Energy. The subsequent report (Knight, 2009 - Phosphorus and Nitrogen Loading and Export from Rhodhiss Lake, North Carolina) identified that 39% of the TP received into Lake Rhodhiss originated from non-point sources from the inflows of the 10 tributaries and the upstream reservoir inflow into Lake Rhodhiss and 61% came from three municipal WWTP point sources. In addition, the report concluded that 54% of the total phosphorus input to Lake Rhodhiss was released downstream into Lake Hickory. As a result of this report, a Lake Rhodhiss Watershed Restoration Plan was prepared by Western Piedmont Council of Government.

The 2011-2012 NCDWQ sampling of Lake Rhodhiss (NCDWQ, 2013) had exhibited only one pH value that exceeded 9.0 and one chlorophyll value greater than 30ɥg/L. Even though Lake Rhodhiss is on the 303d list for impaired waters (high pH), the NCDWQ (2013) reported much fewer exceedances of state water quality standards than in 2004 and 2007. No taste and odor problems were noted since 2002. However, in August 2012, algal densities were classified as a severe bloom, which included *Cylindrospermopsis,* a nitrogen fixing, blue-green algae, known to exhibit taste and odor problems.

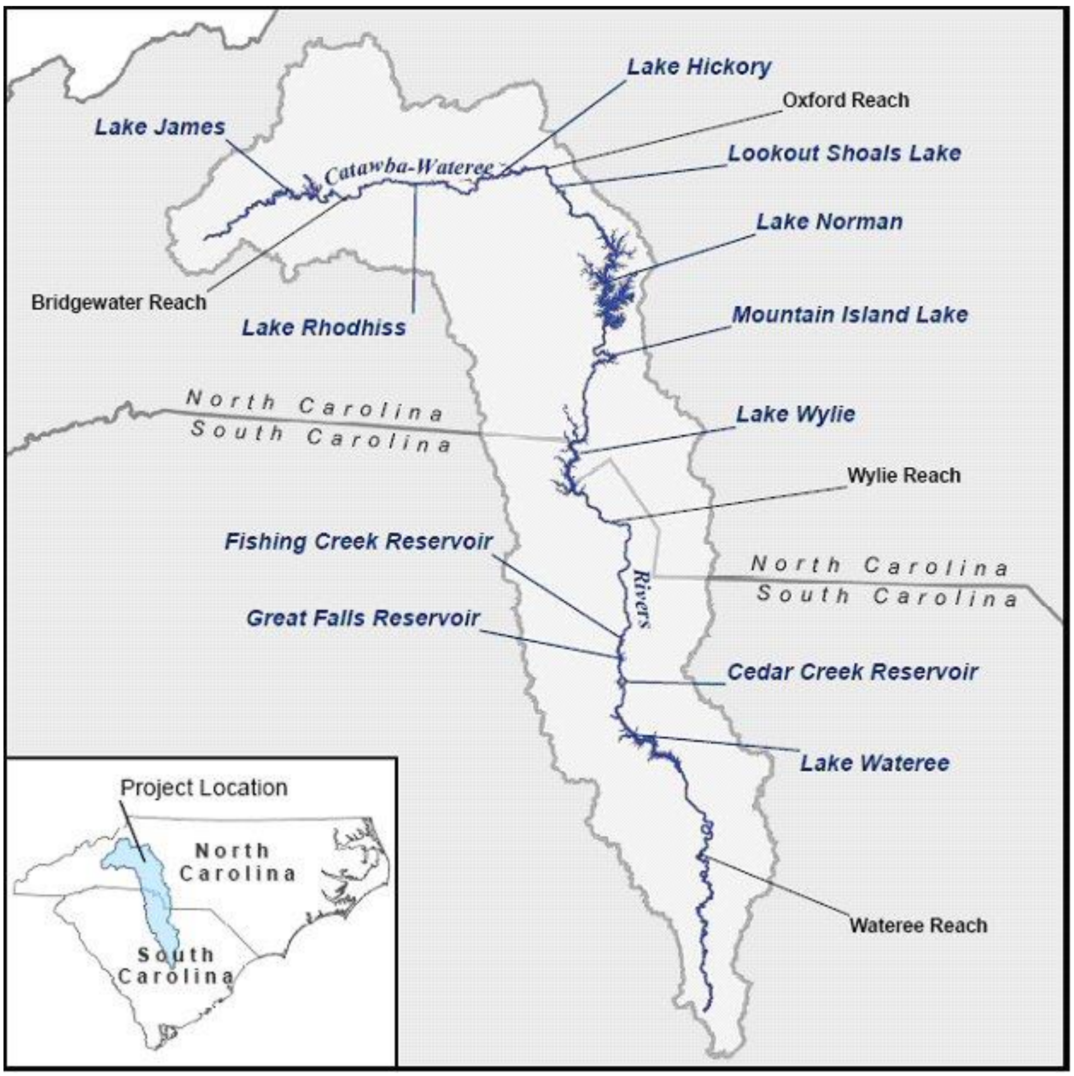
In 2009, a proposal to review and analyze the historic nutrient levels (phosphorus and nitrogen) in Lake Rhodhiss, as related to flow and subsequent algal blooms, was funded by the Catawba-Wateree Water Management Group (WMG). The objectives of this report were to:

1. Evaluate the historic-in-lake water quality data compared to NC State Water Quality Standards,
2. Evaluate the historical nutrient loading and export from Lake Rhodhiss, and, to utilize the historic in-lake data from NCDWQ, Duke Energy, and the USGS for lake dynamics, nutrient levels, and biological activity as related to nutrient loading and export, and,
3. Evaluate the historical nutrient concentrations measured in the Rhodhiss Tailrace as a measure of overall reservoir water quality.

2. SITE DESCRIPTION, DATA SOURCES, AND WATER QUALITY STATISTICS

Rhodhiss Lake is the second most upstream reservoir on the Catawba River (Figure 1). Located between Lakes James and Hickory, Rhodhiss Lake was impounded in 1925 following the completion of Rhodhiss Dam and Powerhouse. Historically, Duke Energy used the hydroelectric station to generate electricity during periods of peak electrical demand and/or during periods of adequate inflows to maintain target lake elevations. In addition to hydropower production, the lake provides drinking water to the municipalities of Granite Falls, Morganton, Lenoir and Valdese. The lake is also popular among fishermen and boaters.

Figure 1. Impoundments on the Catawba River, North and South Carolina.



Rhodhiss Lake is characterized by a short retention time (14.5 days on average) (Table 1). With minimum storage capability, relatively high inflows, relatively shallow depths, and a large watershed, Lake Rhodhiss is dynamic and, typically, inflow driven.

Table 1. Summary Characteristics of Rhodhiss Lake (updated from Duke Energy, 2007)

Parameter	Metric Units	English Units
NCDENR-DWQ Designated Use Classifications	WS-IV, B; CA	N/A
Full Pond (Spillway Elevation)	303.3 m-msl	995.1 ft-msl
Mean Lake Elevation[4]	302.2 m-msl	991.4 ft.msl
Surface Area[1]	1102 ha	2724 acres
Volume[1]	5.736×10^7 cubic meters	46,500 acre-feet
Maximum Depth[1]	18.0 meters	59 feet
Mean Depth[1]	6.3 meters	20.6 feet
Shoreline[1]	171.8 kilometers	106.8 miles
Total Watershed Area[2]	2823 sq. kilometers	1090 sq. miles
Reservoir Direct Watershed Area[3]	1827 sq. kilometers	703.5 sq. miles
Mean Inflow[4]	50.43 cubic meters per sec	1781 cubic feet per sec
Mean Outflow[4]	45.65 cubic meters per sec	1612 cubic feet per sec
Mean Retention Time[4]	14.5 days	N/A
Retention Time (Range)[4]	4 - 100 days	N/A

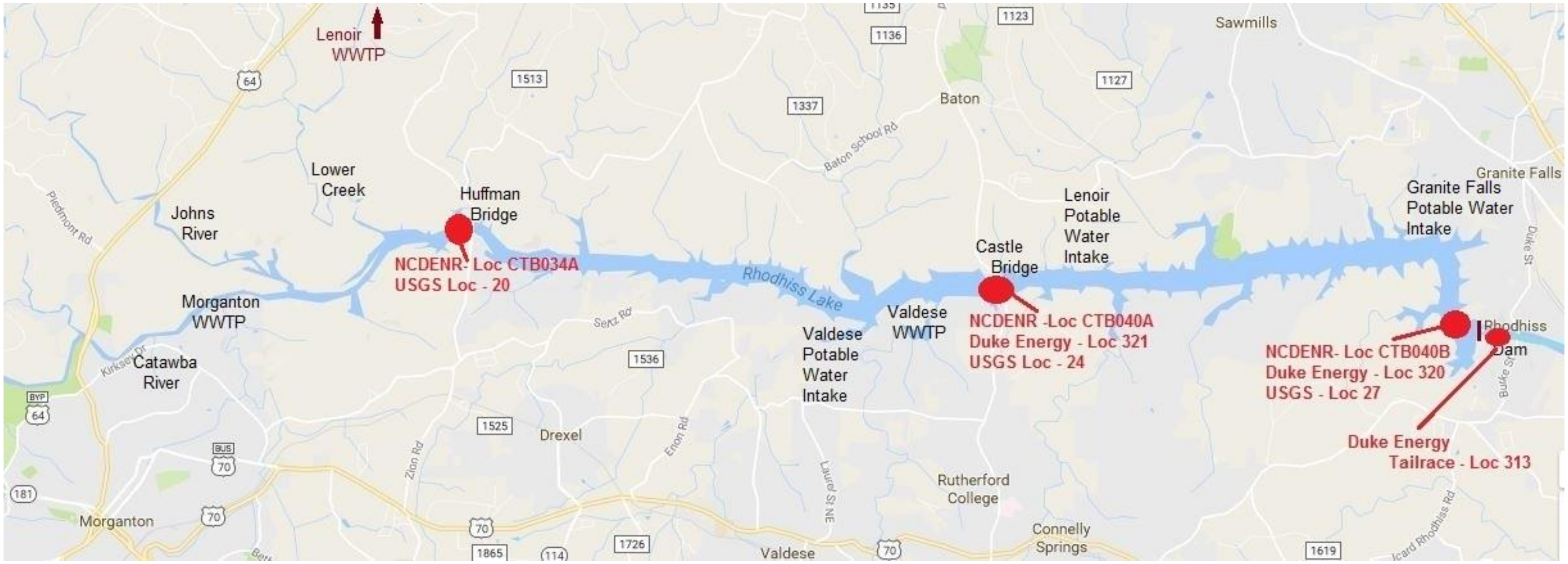
[1]Values Calculated from full pond (995.1 ft-msl)
[2]Up-stream Reservoir Included
[3]Does Not Include Up-stream Reservoir
[4]Based upon monthly averages from 1929 – 2003

This report included a 5-year continuation of a bi-monthly sampling of total nitrogen and total phosphorus in the Rhodhiss tailrace began by Duke Energy in 1997. Continuation of the tailrace sampling through the summer of 2014, administered by Carolina Land & Lakes (CL&L), was conducted by the Hickory Pretreatment staff, sample transport and analysis was provided by Duke Energy.

Historical data was provided by the following:

Duke Energy –	lake water quality data	1960 - 2004
	tailrace water quality data	1973 - 2004
	Hydro flows	1973 – 2014
USEPA -	lake water quality data	1973
NCDWQ -	lake water quality data	1981 – 2014
DMR from WWTP -	Valdese	1997 - 2014
	Morganton	1998 - 2014
	Lenoir	2003 - 2014
USGS -	lake water quality data	1993 – 1994
CL&L -	tailrace water quality data	2009 – 2014
	tributary nutrient loading	2007 – 2008

Figure 2. Map of Lake Rhodhiss Water Quality Sampling Locations, Potable Water Intakes, WWTP Discharges



A water quality data base was compiled from all the sources for each of the sampling sites shown in Figure 2. The Castle Bridge and Forebay locations were sampled by the NCDENR, Duke Energy, and the USGS. Duke did not sample at the Huffman Bridge except during Duke's relicensing (2004). Even though the primary emphasis of this report is on the lower reservoir sites and the tailrace, the Huffman Bridge site was included since the NCDENR has referenced this site numerous times for exceedence of water quality standards and served as a reference for the water quality entering the lake .

Table 2. North Carolina State Water Quality Standards for Lake Rhodhiss

North Carolina 15A NCAC 02B Surface Water Quality Standards

Last updated 6/30/2016 - Check here to see if a more recent version is available.

All values in ug/L unless noted below. Values in **red** are 15A NCAC 02B Water Quality Standards.

Pollutant or Parameter	Freshwater Aquatic Life	Water Supply[2]	Human Health[3]	Synonyms & Other Information	Data Reference Source
Chlorophyll-a, Corrected	**40** (N)			See 15A NCAC 02B .0211 and .0220	NC
Dissolved Gases	**110%** sat (N)			See 15A NCAC 02B .0211 and .0220	NC
Dissolved Oxygen	**≥5.0** mg/L (N)			See 15A NCAC 02B .0211 and .0220	NC
Nitrate nitrogen		**10** mg/L		Nutrient parameters may be regulated in nutrient sensitive waters (NSW). See 15A NCAC 02B .0223.	NC
pH	**6.0-9.0** (N)			See 15A NCAC 02B .0211 and .0220	
Sewage	**(N)**	**(N)**		See 15A NCAC 02B .0211, .0212 and .0220	NC
Solids, Settleable	**(N)**			See 15A NCAC 02B .0211 and .0220.Also includes floating solids and sludge deposits.	NC
Temperature	**(N)**		**(N)**	NCAC 02B .0208, .0211, and .0220	NC
Turbidity	**50/25** NTU (N)			See 15A NCAC 02B .0211 and .0220. NTU = Nephelometric Turbidity Units	NC

Footnotes, Codes and Additional Information with Reference to Classifications & Standards

Values in red font are 15A NCAC 02B standards

(N) = narrative standard.

The standards in this table are developed per section 15A NCAC 02B of the North Carolina Administrative Code. To determine the appropriate standard, use the most stringent of all applicable columns as described below.

(2) Water Supply standards are applicable to all Water Supply Classifications and are based on consumption of fish and water. See 15A NCAC 02B .0208, .0212, .0214, .0215, .0216, and .0218.

(3) Human Health standards are based on the consumption of fish only unless dermal contact studies are available. See 15A NCAC 02B .0208.

Table 3. Summary Statistics of Rhodhiss Lake Water Quality Data, 1993-2014 (Compilation of all available data).

Water Quality Parameter	units	Tailrace			Forebay			Castle Bridge			Huffman Bridge		
		Median	min	max	Median	min	max	Median	min	max	Median	min	max
Secchi Disc Depth	m	-	-	-	1.2	0.1	2.9	1.0	0.2	1.8	0.6	0.2	1.6
Turbidity	NTU	7.5	2.62	44	3.6	1.60	76	5.40	1.28	69	17.00	2.10	118
Suspended Solids	mg/L	3.7	0.94	121	6.2	3.00	17	6.20	0.73	39	25.26	6.00	86
Chorophyll	цg/l	-	-	-	10.4	0.10	50	14.30	0.10	69	2.03	0.20	70
Dissolved Oxygen	mg/L	6.60	5.79	9.34	6.87	0.00	14.10	7.27	0.10	14.90	7.70	4.00	11.70
pH		6.45	5.81	7.29	6.76	5.80	9.70	7.00	5.98	9.90	7.00	6.19	9.10
Conductivity	цSi/cm	60	42	71	65	31	150	62	30	203	55	32	177
Nutrients													
TP	mg/l	0.040	0.015	0.185	0.037	0.008	0.320	0.043	0.010	0.170	0.056	0.010	0.154
NO_3	mg/l	0.220	0.070	0.450	0.160	0.005	0.660	0.125	0.005	0.300	0.240	0.006	0.450
TKN	mg/l	0.300	0.100	0.700	0.300	0.100	2.070	0.320	0.100	0.900	0.300	0.100	0.800
N:P		30	-		28	-		24	-		22	-	
Σ Anions		*0.61*			*0.57*			*0.54*			*0.43*		
HCO_3	meq/l	0.33	0.16	0.52	0.30	0.03	0.78	0.32	0.03	0.98	0.30	0.20	0.68
Cl	meq/l	0.16	0.08	0.29	0.16	0.00	0.50	0.13	0.07	0.41	0.07	0.06	0.10
SO_4	meq/l	0.12	0.07	0.21	0.10	0.06	0.29	0.09	0.06	0.21	0.06	0.05	0.07
Σ Cations		*0.63*			*0.57*			*0.52*			*0.43*		
Na	meq/l	0.32	0.12	0.55	0.29	0.12	0.62	0.24	0.13	0.65	0.13	0.12	0.18
K	meq/l	0.04	0.03	0.06	0.04	0.03	0.05	0.04	1.17	0.65	0.04	0.03	0.05
Ca	meq/l	0.15	0.10	0.24	0.14	0.10	0.26	0.14	0.10	0.05	0.15	0.10	0.20
Mg	meq/l	0.12	0.07	0.15	0.10	0.06	0.14	0.10	0.07	0.13	0.11	0.07	0.13
Mn	mg/l	0.01	0.01	0.15	0.05	0.01	18.50	0.04	0.01	0.29	0.08	0.06	0.15
Fe	mg/l	0.17	0.04	2.12	0.25	0.02	13.70	0.41	0.08	3.58	0.91	0.31	5.18
	Some values exceeded State Water Quality Standards												
	Some values were lower than State Water Quality Standards												

The summary water quality statistics (Table 3) provided a generalized pattern of reservoir behavior. Namely, the median seechi disc depths, turbidity and suspended solids trends reflect suspended sediment entering the lake and gradually settling out in the lake as the water progresses downstream in the reservoir.[1] Also the highest median chlorophyll values were observed in the mid-way transition zone, which is a typical reservoir characteristic (Thornton, et al, 1990). However, all lake locations periodically experienced high chlorophyll concentrations. The high dissolved oxygen and pH values were a result of pulses of high productivity in the surface waters, and, conversely, low dissolved oxygen and pH values were indicative of decomposition/respiration in the lower layers of the lake. Small changes of CO_2, either removed by photosynthesis or added due to decomposition/respiration would change the pH significantly due to the very low buffering capacity, i.e. very low alkalinity.

[1] Huffman Bridge is located immediately downstream of the major inflows, i.e. the Catawba River, Warrior Fork, Johns River and Lower Creek and immediately downstream of the Morganton WWTP (Lenoir's WWTP discharges into Lower Creek).

The concentrations and ratios of the major anions and cations were very consistent with other piedmont waters originating from the weathering of igneous rock formations in the watershed. The range of iron and manganese concentrations were a function of the composition of the residual clays and potential release of iron and manganese under reduced conditions, i.e. low dissolved oxygen in the lower depths.

Even though the median concentrations of phosphorus and nitrogen indicate little change through the reservoir, the ranges of all nutrients at all locations indicate significant interaction and dynamics within the lake. The median 29% reduction of phosphorus concentrations between the inflow and outflow indicated that phosphorus was retained within the reservoir; however, significant variability in phosphorus concentrations was observed. Median nitrogen concentrations were fairly similar throughout the system, but again, as with phosphorus, exhibited great variability. Based upon an average Trophic State Index (TSI) presented in Wetzel (2001), the comparison of the median Chlorophyll to Phosphorus TSI to the median Chlorophyll to Seechi disc TSI indicated that the lake was predominantly controlled by clay turbidity.

A net nutrient balance (Table 4) revealed that, overall, Lake Rhodhiss retained or lost 46.6% of the yearly phosphorus input and 35.7% of the yearly nitrogen input. The molar N:P ratios suggest that tributary inflows were phosphate limited to plankton growth while the WWTP input was phosphorus rich, relative to nitrogen. Based upon the ideal molar ratio of 23 (see N:P ratios discussed in Wetzel, 2001), the yearly lake nutrient mass exchanges (total input and total output) were suggestive of nitrogen being slightly limiting to algal growth within the reservoir. Although the net balance does not account for specific timing or spatial differences of in-lake mechanisms within the reservoir, the balance does reveal a significant loss of both nutrients from Lake Rhodhiss exported to Lake Hickory. Reservoirs exhibiting short hydraulic retention times characteristically retain 50-70% of the loaded phosphorus (Wetzel, 2001).

Table 4. Net Nutrient Balance for Lake Rhodhiss, 2007. (Compiled from Knight, 2009).

Note: All values are Metric Tons per year		**Phosphorus**	**Nitrogen**	**Molar N:P**
Input	Total of Tributaries (non-point Source)	**23.0**	**290.3**	***29***
	Total of WWTP (point Source)	**36.0**	**191.6**	***12***
	Total Input	**59.0**	**481.9**	***19***
Outlet	Rhodhiss Hydro	**31.6**	**310.1**	***22***
Difference		**27.5**	**171.8**	***14***

Two separate attempts (Giorgino and Bales, 1997, and Jain and Ruane, 2006) modeled the water quality of Lake Rhodhiss using the two-dimensional hydrodynamic water quality model CE-QUAL-W2. Giorgino and Bales showed a simulated 30% reduced point source phosphorus load resulted in a 20% reduction of maximum algal concentrations, especially in late summer and early fall. Similarly, an increase in phosphate load from the Valdese WWTP discharge (pipe on the bottom of the lake) had little impact on algal concentrations. But, when the increase was applied to a simulated surface WWTP discharge, algal concentrations increased 2-3 times compared to the simulations of the bottom discharge. The Jain and Ruane model emphasized that nutrient patterns were very dynamic, and were driven by loadings that got diluted and redistributed by intermittent reservoir flow. In addition, phosphorus contributions due to point source and non-point discharges were not fully processed or utilized by the plankton before being released from the dam. The median and ranges of measured nutrient concentrations (Table 3) support their conclusion. The model also predicted that at high inflows, algal blooms were limited by short retention times. Low inflows (high retention times, high light penetration, and favorable nutrient concentrations) allowed algal blooms to develop and persist. These higher algal populations triggered high pH and DO values in the upper water column.

3. DETAILED WATER QUALITY ANALYSIS

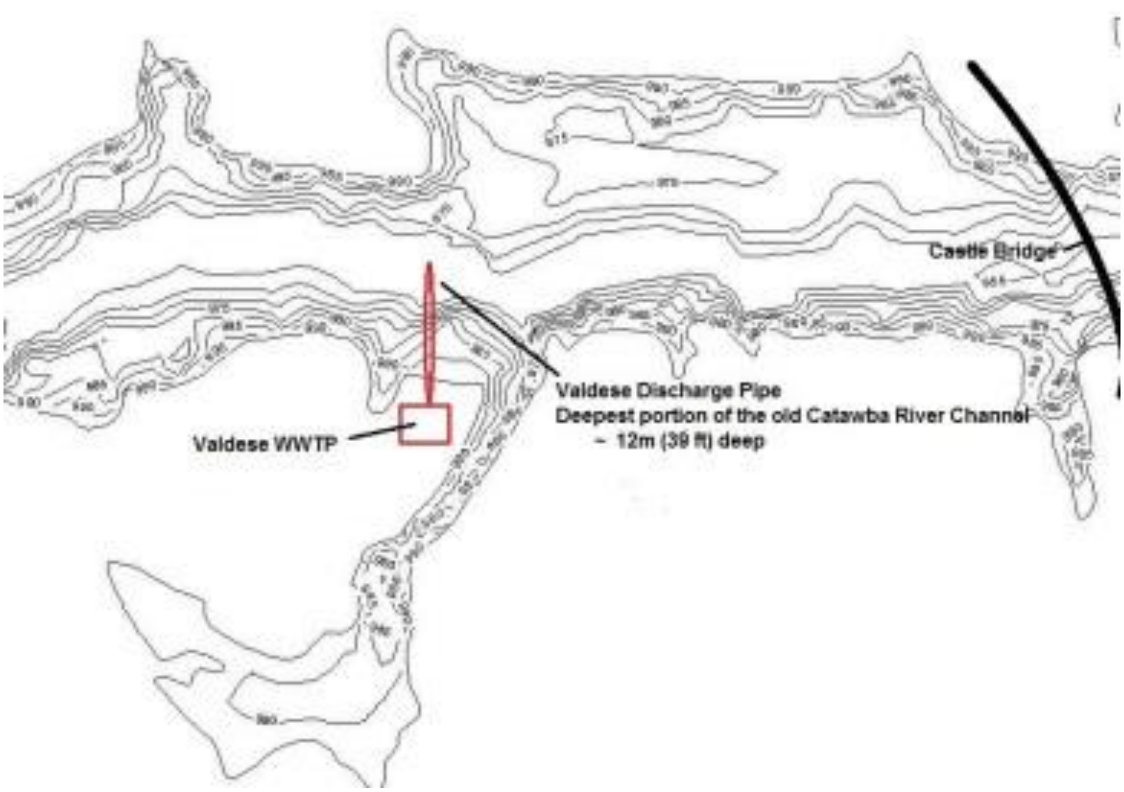
The previous section described generalizations of reservoir characteristics based upon medians and ranges of the various water quality parameters. This section investigates the role of bathymetry (physical structures), hydrological events, light penetration, point and non-point nutrient sources that impact algal standing stocks and nutrient releases to Lake Hickory.

3.1 Physical Structures

3.1.1 Valdese WWTP Discharge

The depth of the Valdese discharge pipe (Figure 3), as (Giorgino and Bales, 1997) modeled, was a major factor in the distribution of point source derived nutrients in the lake. The discharge depth was intentionally placed at the maximum depth in the old Catawba River channel to take advantage of the density driven currents of the cooler inflow to keep the effluent in the deeper portions of the lake.

Figure 3. Plan View of Valdese WWTP Discharge

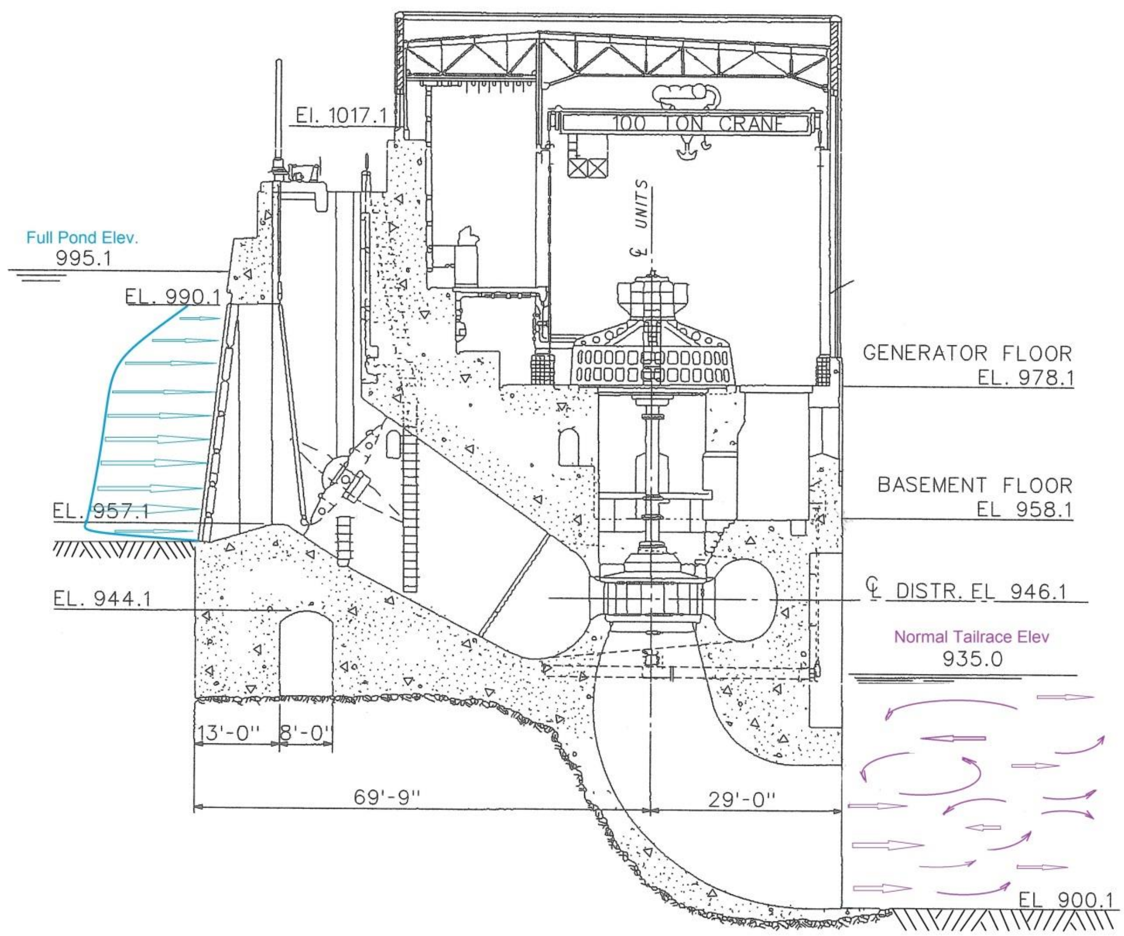


3.1.2 Rhodhiss Hydro

Water velocities, as reported by Duke Energy (2007), for both the hydro intake (blue arrows, Figure 4) and the tailrace (purple arrows, Figure 4) exhibited very different characteristics of water flow. The forebay withdrawal zone (lake surface to lake bottom) had the greatest flow from the intake invert (elev. = 957.1 msl) upwards. Above elev.≈ 978 msl, the velocities gradually decreased towards the surface. During high intake flow rates, the withdrawal zone expanded with increased velocities towards the surface. At low flows, surface velocities decreased, with the maximum velocities at or above the invert. The net result of the withdrawal zone was that the majority of the water released downstream originated from the deeper depths of Lake Rhodhiss.

The velocities in the tailrace showed a net movement downstream with high turbulent mixing throughout the tailrace depths (illustrated by the purple vectors in Figure 4). Due to the high turbulence, the water samples collected in the tailrace represented an integral of the forebay water column determined by the withdrawal zone characteristics. Under most conditions, the water at the deeper depths in the reservoir composed most of the water released downstream.

Figure 4. Cross Section of Rhodhiss Hydro, Illustrating Approximate Water Velocities (Size of Blue Arrows represent approximate intake velocities at depth, Size of Purple Arrows represent approximate discharge velocities at depth)

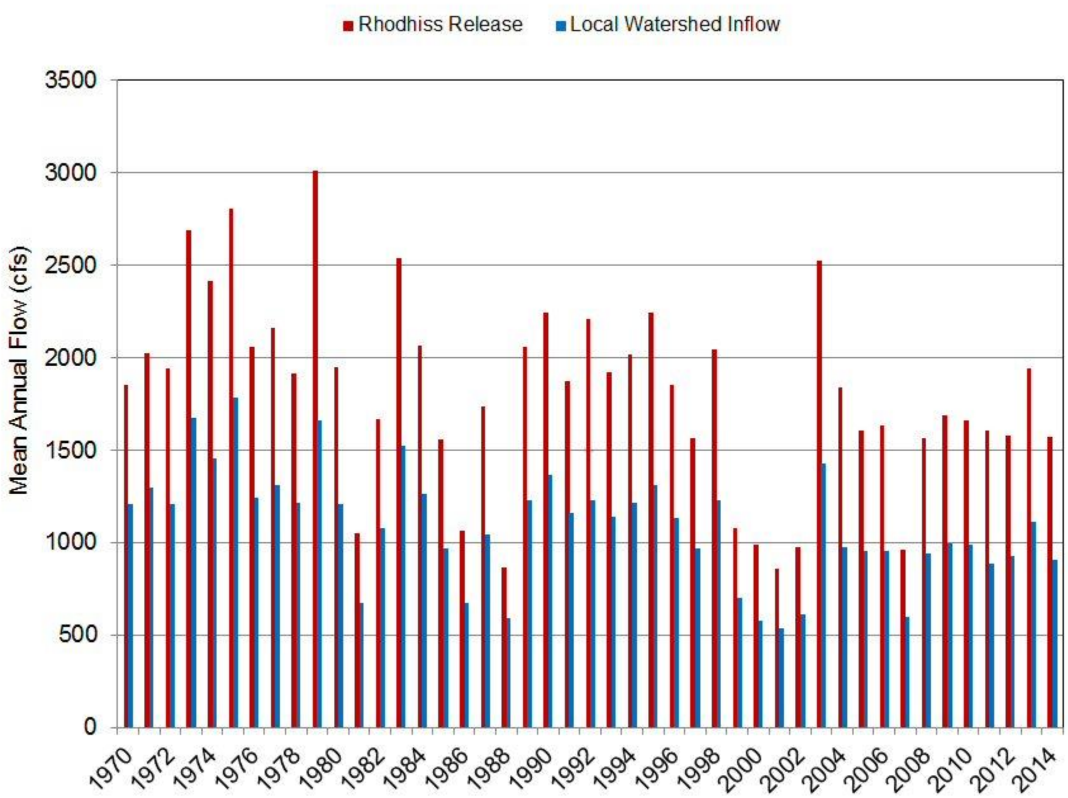


3.2 Hydrology

Duke Energy (2007) calculated a daily lake water balance for each reservoir on the Catawba River for incorporation into an Hydrologic/Hydraulic Operations Model (CHEOPS©) used for various operational scenarios during the relicensing process. The water balances were completed through 2004. For this report, the Duke water balance calculations were expanded to include actual operating data (daily generation, reservoir level, and spill) for the 2005-2014 period. The primary variables calculated from the daily water balances used for this report include: (1) Bridgewater and Rhodhiss generation flows and spill flows and, (2) local watershed inflows. Daily values were averaged to obtain monthly averages, which, in turn, were used to calculate yearly averages.

The mean flow from Lake Rhodhiss over the 44 years was 1811 cfs, with the lowest flow of 857 cfs recorded in 2001 and the highest average flow of 3011 cfs observed in 1979 Figure 5). The local watersheds contributed between 52 and 67 percent of the water inflow to Rhodhiss, these percentages were not correlated with the total amount water released from Rhodhiss but they do impact the amount of nutrient loading from non-point sources (see Section 3.5).

Figure 5. Lake Rhodhiss Mean Annual Flow from Rhodhiss Hydro and the Local Watershed, 1970-2014.



Average annual hydraulic retention times were useful generic information, but seasonal retention times actually drive the metabolic process within a reservoir. Average seasonal retention times were calculated for each year (Figure 6). The seasonal periods were based upon the typical periods characteristic of Piedmont, monomictic lakes which exhibit 3 major periods throughout the year, namely: (1) a winter period (Oct-Feb) characterized by whole lake cooling which results in uniform water column temperatures (maximum vertical mixing), and exhibited decreased algal populations limited by mixing, low light, and low temperatures, (2) a spring period (Mar-June) of gradual to rapid warming, with the development of increased thermal stratification and reduced vertical mixing, and larger algal populations which prefer cool water, high light, and abundant nutrients, and, (3) a summer period (Jul-Sep) where the water column was characterized by warm surface temperatures and cooler bottom temperatures which exhibit maximum lake thermal stratification (minimum vertical mixing), the season was usually dominated by warm water algal communities preferring high light, minimum vertical mixing and, potentially, low nutrient levels.

Figure 6. Lake Rhodhiss Mean Seasonal Hydraulic Retention Times, 1970-2014

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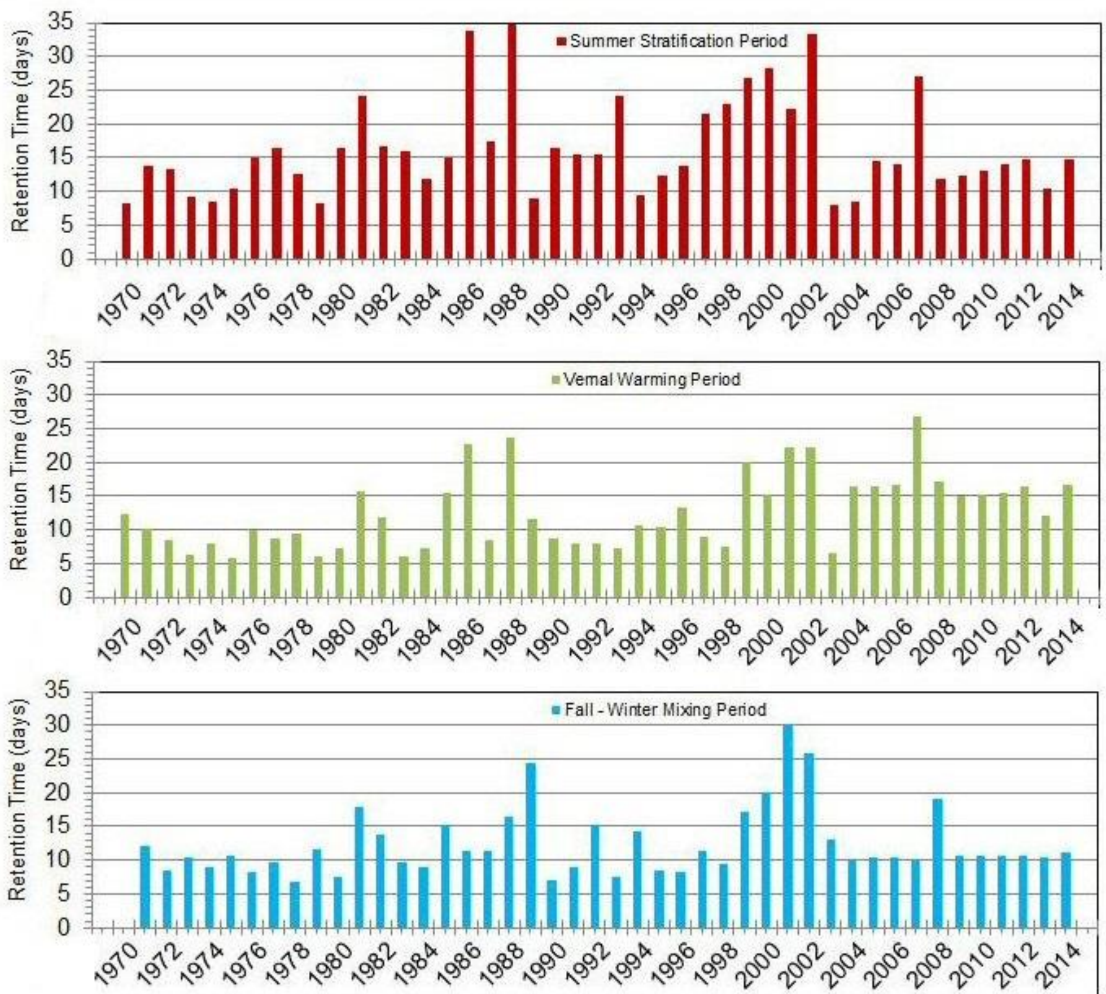


With few exceptions, the fall-winter retention times were less than 15 days: 1989 and 1999-2002 had longer retention of water in the winter (usually the period of higher inflows). The spring warming period had, on the average, slightly higher retention times than the winter months, with 6 years experiencing retention times greater than 20 days. The summer period had 11 years greater than 20 days, 6 years greater than 25 days, and 3 years greater than 30 days. Although no minimum specific hydraulic retention time defines the amount of phytoplankton, the shorter the retention times the faster the plankton was flushed out of the system and less time to develop large populations.

3.3 Lake Stratification

Lake stratification is the process by which deeper, cooler layers of water become progressively isolated with a reduced tendency to mix vertically. Typically, the extent and degree of stratification was dependent upon the surface heating (or cooling) and wind mixing. However, significant inflow to reservoirs may result in advective induced stratification (Thornton, et al, 1990). This appears to be the case for Rhodhiss reservoir. Temperature profiles, both in May and August, show remarkably similar patterns between the four years representing a range of retention times (Figures 7A and 7B) indicating that the substantial inflow dominated the stratification process as well as the water column withdrawal zone induced by Rhodhiss hydro (Figure 4). The dominance of advective flow was also noticeable by the similar increases of water column temperature between May and August for each year. Stratification due to surface warming was limited to the upper few meters of the water column.

Even though the temperature profiles did not exhibit a strong thermocline (not expected during high advective flow), a stable water column (minimum vertical mixing) was evident by the vertical dissolved oxygen concentrations and pH gradients. Both parameters were heavily influenced by the plankton communities, i.e. photosynthesis in the euphotic zone[2] adds O_2 and removes CO_2 while respiration and bacterial decomposition rates dominated in the lower depths (Figure 6). The very low buffering capacity of the lake water (Table 3) enabled significant pH changes due to the addition or removal of CO_2 by the biological processes. Even though the supersaturated oxygen concentrations in the euphotic zone and high pH levels (> 9.0) exceed state water quality standards (Figure 7 and 8) these exceedances were indicators of high levels of phytoplankton production. Dissolved oxygen concentrations and pH values would probably decrease to below state standards at night as photosynthesis diminished with the onset of darkness. Unfortunately no night time data were recorded.

However, these high algal production rates were not mirrored in significant increases of algal standing crops as measured by chlorophyll concentrations. Rather, the phytoplankton production was either respired by the plankton themselves or settled to the deeper depths where bacterial decomposition consumed them. Also, transfer of phytoplankton production to higher trophic levels (zooplankton and/or fish) contributed to the overall biological production of the Rhodhiss ecosystem.

In 2008, the North Carolina 303(d) list was updated to include Rhodhiss Lake for exhibiting high pH values (and presumably high DO saturation values) based upon the observations collected in the late 1990's and through 2004. Even though the NCDWQ observed lower pH and DO values from the 2011 and 2012 sampling, Rhodhiss Lake remained on the 303d list. Based upon the sample collections of NCDWQ and the availability of data, three distinct periods were used for water quality trend analysis, namely: data from 1973 – 1995, data from 1996 -2005, and data from 2006 -2014.

The history of the frequency of occurrences of all measurements of pH and dissolved oxygen concentrations made in the euphotic (surface) zone (Figure 8) reveal that since 1973, 10-20% of the pH measurements exceeded the state standard and 25-45 % of the percent DO saturation values exceeded state water quality standard. As mentioned previously, the higher pH and dissolved oxygen levels indicate that the photosynthetic rates of the plankton dominated the metabolic activity. A general trend of progressively higher pH's towards the forebay was observed for all of the years; dissolved oxygen values also increased in the euphotic zone closer to the dam. The pH values exhibited an overall rise throughout the years. DO concentrations did not follow a similar increase.

The frequency of occurrence of chlorophyll concentrations had a different trend. The chlorophyll measured in 2006-2014 had a higher frequency of concentrations in the 15-20 ug/L range than previous years. But the chlorophylls measured from 1996-2004 period had the highest frequency of high concentrations. These high chlorophyll values occurred during the time with the longest hydraulic retention times. Even though there was not a direct correlation between chlorophyll concentrations and hydraulic retention time, high retention times do seem to promote high phytoplankton populations.

[2] approximated by 2 times the Seechi disk depth

Figure 7A. May Lake Rhodhiss Profiles for High Spring Retention Times (2001 and 2007), Low Retention Time (2004), and Mean Retention Time (2012)

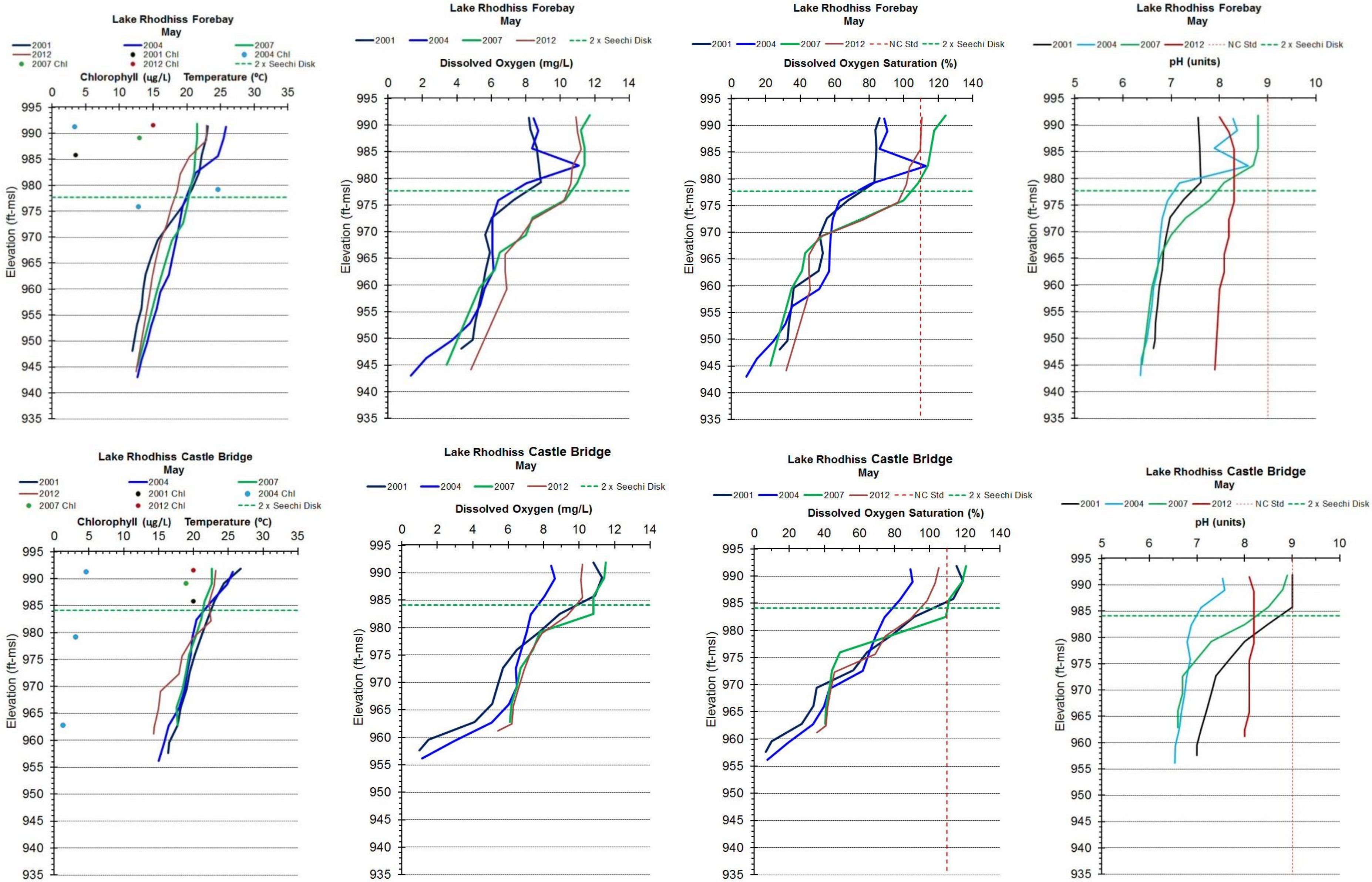


Figure 7B. August Lake Rhodhiss Profiles for High Summer Retention Times (2001 and 2007), Low Retention Time (2004), and Mean Retention Time (2012)

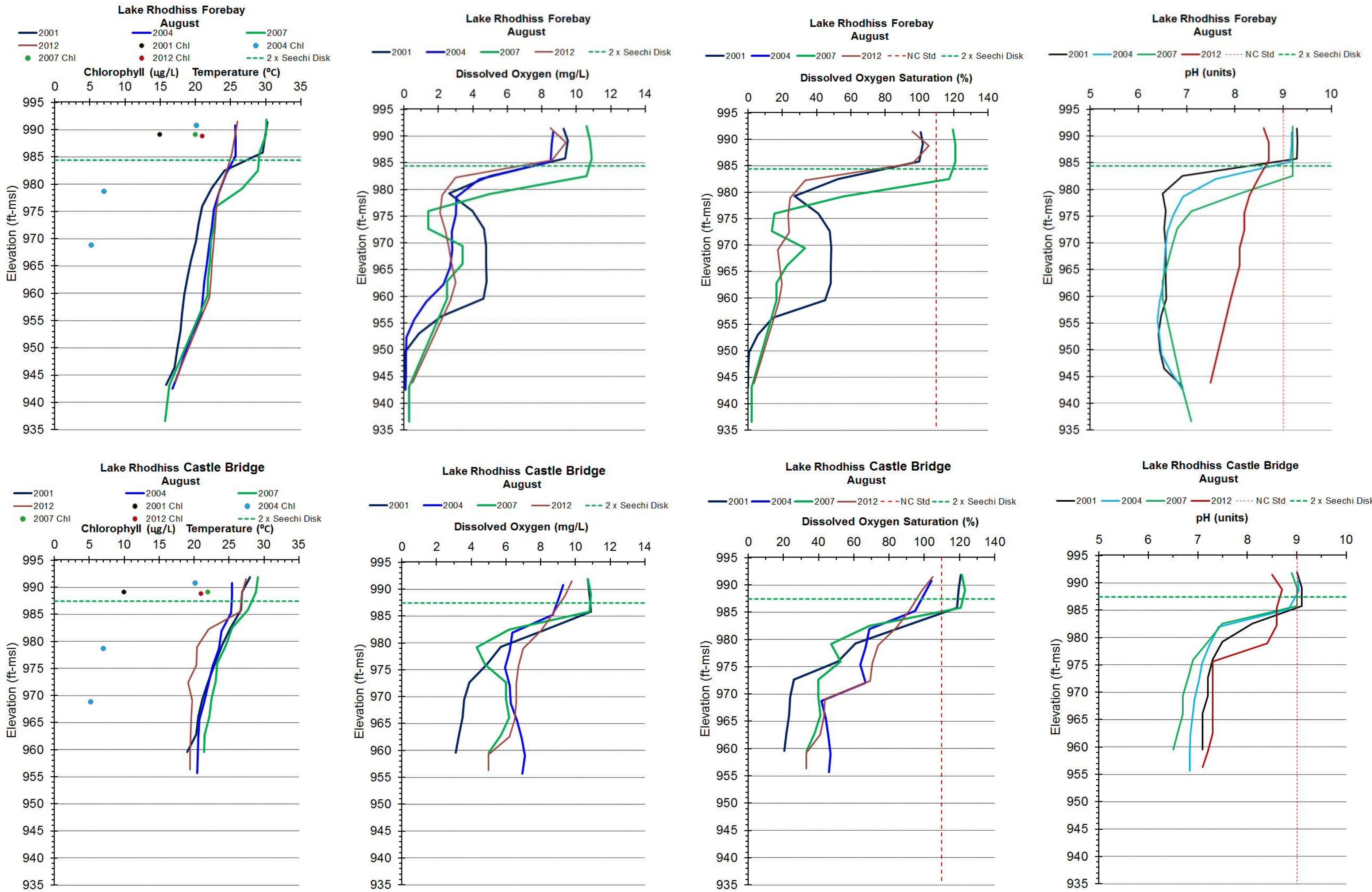
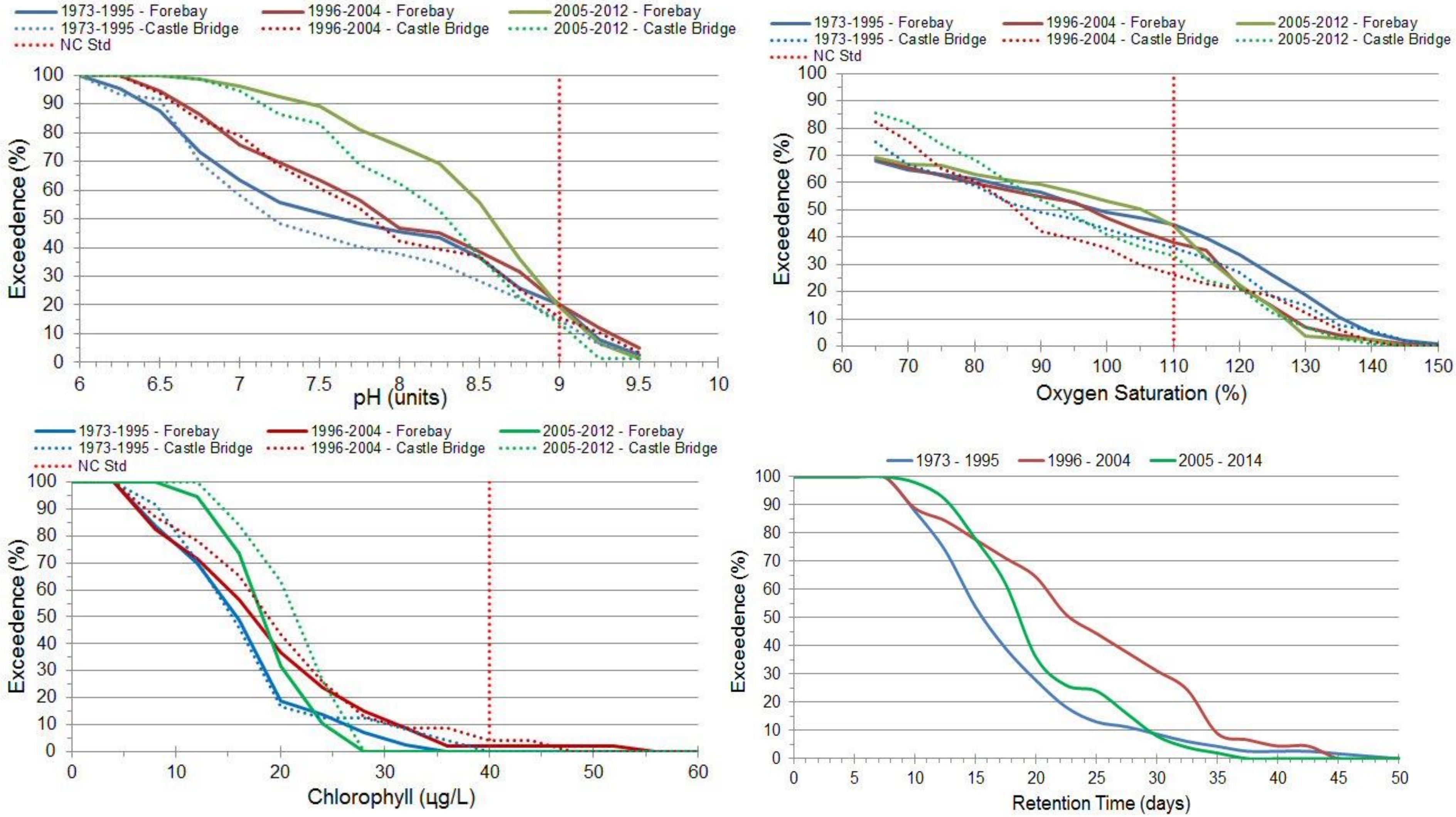


Figure 8. Frequency of Occurrence of pH, O_2 , and O_2 Sat Measured in the Upper 6 m of Rhodhiss Lake and the total Reservoir Retention Time, May-Sept.



3.4 Nitrogen and Phosphorus Concentrations

All of the total nitrogen (nitrate-N plus Kjelhahl-N) and total phosphorus (TP) samples collected from Rhodhiss Lake exhibited a wide range of concentrations with no discernable trends (Figures 9-10). The numbers of samples from the three locations and the number of samples collected each year over the 42 year period was a function of the priorities of each organization that collected the data. Even though nitrate-nitrogen (NO_3-N) samples were collected about the same frequency as total phosphorus, far fewer total Kjelhahl nitrogen (TKN) samples were analyzed, especially in the early years[3] preventing the calculation of total nitrogen.

The most complete yearly nutrient data set was collected by the USGS in 1993 (Giorgino and Bales, 1997). Not only did they collect TP, NO_3-N, and TKN in the surface water, but also collected these parameters from the deeper depths in Lake Rhodhiss. Their data, along with quarterly data collected by Duke Energy, enabled a fairly complete analysis of nutrient trends within the lake (Figures 11-13). This was particularly useful since1993 was a year with relatively high spring inflows from the local watershed (presumably high non-point phosphorus sources) and 1993 exhibited relatively high retention times during the summer growing season (Figure 6).

Euphotic zone nitrite nitrogen concentrations collected at the Huffman Bridge were consistently lower than nitrate observed at the Castle Bridge and Forebay sites (Figure 11A). Even though there was a slight increase in nitrate during the peak runoff in March, the majority of the nitrate in the lower reservoir probably originated from the Valdese WWTP. The Huffman Bridge site was downstream of both the Lenoir WWTP[4] and the Morganton WWTP[5]. Both of these discharges probably got diluted from the watershed runoff as well as the flow from Bridgewater. The nitrate concentrations at Huffman Bridge gradually increased during the fall (less dilution water). Most significantly, even though nitrate in the surface water was relatively high in the spring, the NO_3-N concentrations rapidly decreased in the spring and into the summer as the algal populations utilized NO_3-N and converted the nitrogen to particulate organic nitrogen as evidenced by the increase in euphotic zone TKN values in the summer (Figure 11B). At the same time, NO_3-N levels increased in the deeper depths; either as a function of algal sedimentation and subsequent decomposition and/or input from the deep water discharge of the Valdese WWTP. Apparently, rapid decomposition of the settled particulate matter did not allow organic TKN values to accumulate in the lower water.

Phosphorus concentrations in the euphotic zone showed the opposite trend as nitrate-N. Total phosphorus concentrations were consistently higher at the Huffman Bridge and decreased downstream through the reservoir (Figure 11C). Phosphorus concentrations increased during the March storm event as particulate material was transported downstream with the runoff. The phosphorus concentrations at the Huffman Bridge were indicative of phosphate adsorption onto the particulate material and subsequent settling in the reservoir. The phosphate discharged from both the Lenoir and Morganton WWTP's were rapidly adsorbed unto particulate material and, as inflow decreased in late summer, the concentration of phosphorus at the Huffman Bridge gradually rose since less dilution water was available in late summer and early fall. With the adsorption of phosphorus on both inorganic and organic particles and subsequent sedimentation as the water slowed in the reservoir, the phosphorus was removed from the upper euphotic zone and accumulated in the deeper depths (Figures 11C and 12C).

[3] TKN samples collected in 1973 were part of the USEPA nationwide Eutrophication Study (USEP, 1975)
[4] Lenoir WWTP is located on Lower Creek
[5] Morganton WWTP is located on the Catawba River

Figure 9A. Total Nitrogen Concentrations Measured at Huffman and Castle Bridges, 1973-2012.

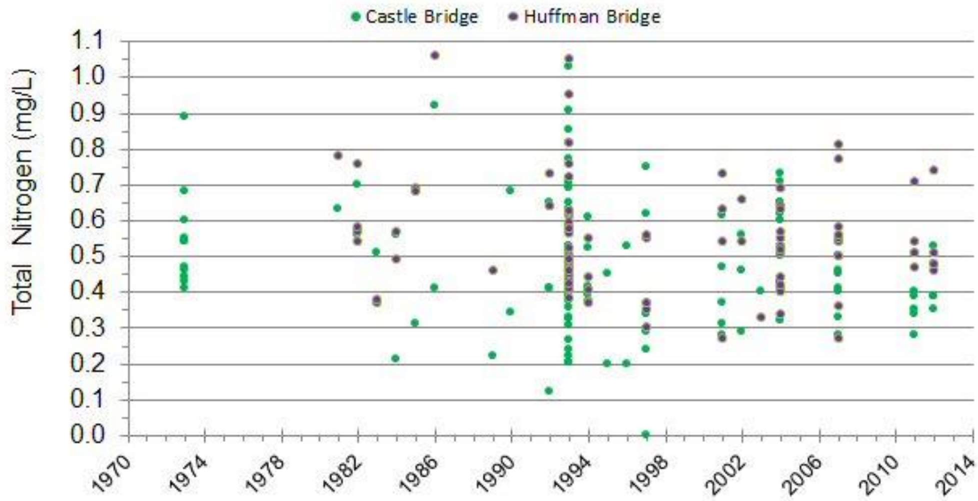


Figure 9B. Total Nitrogen Concentrations Measured at Castle Bridge and Forebay, 1973-2012

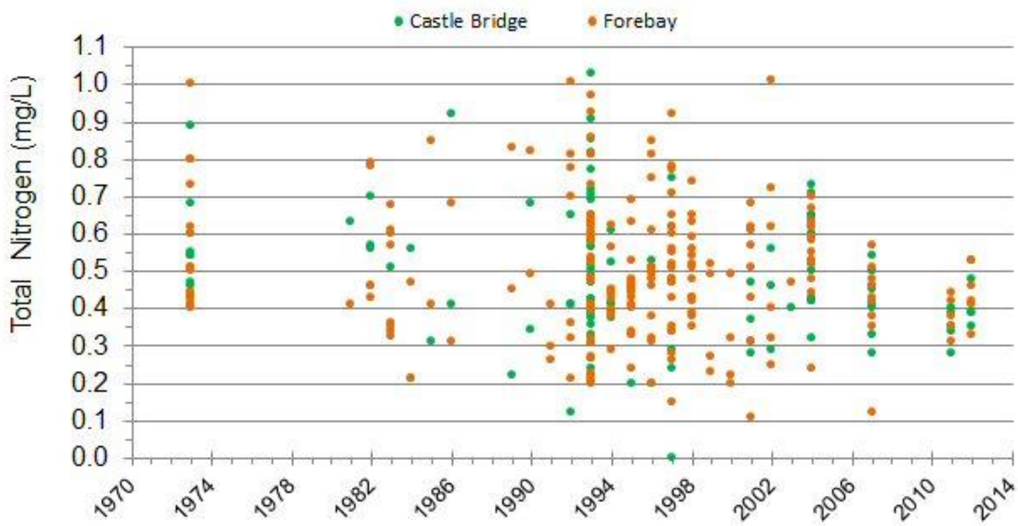


Figure 9C. Total Nitrogen Concentrations Measured at the Forebay and Tailrace, 1973-2014.

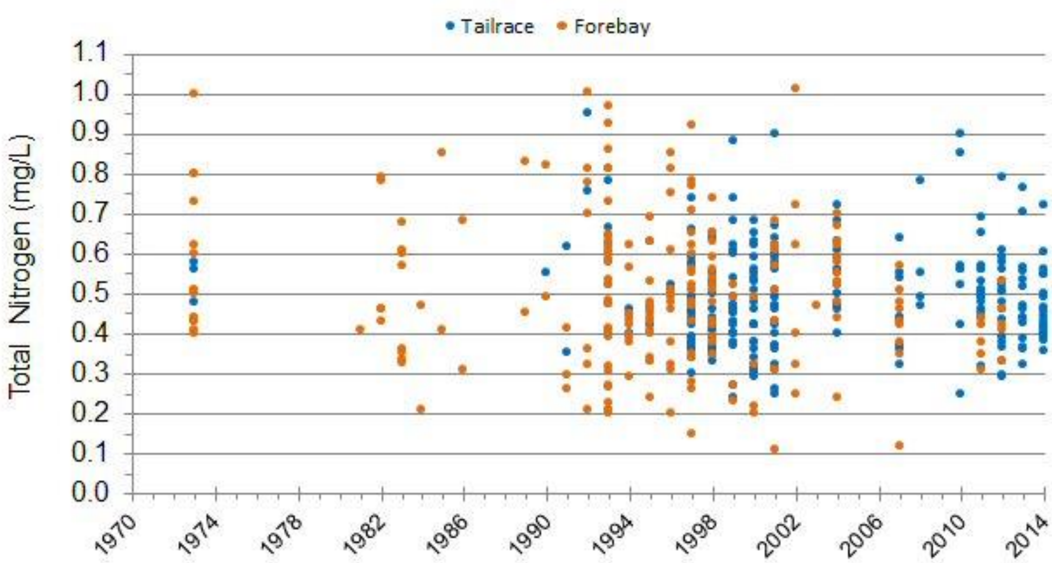


Figure 10A. Total Phosphorus Concentrations Measured at Huffman and Castle Bridges, 1973-2012.

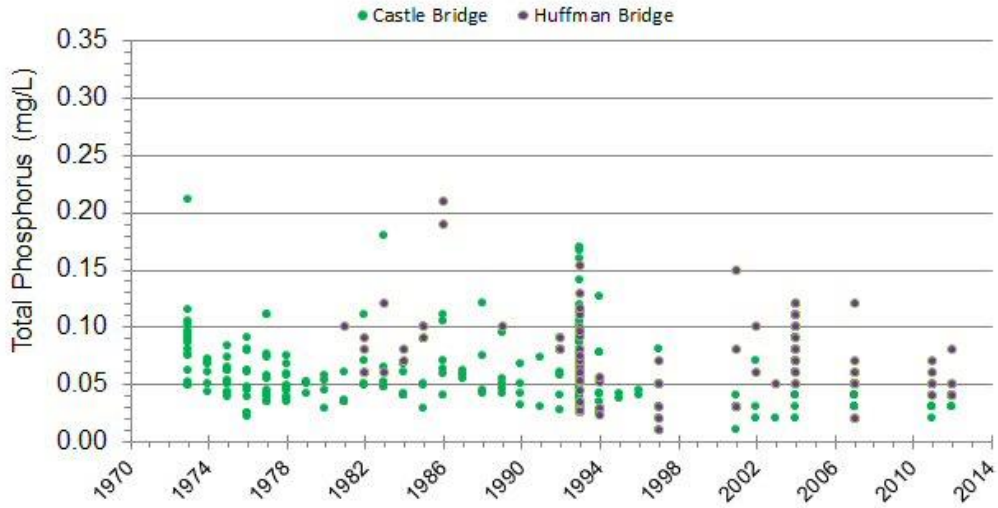


Figure 10B. Total Phosphorus Concentrations Measured at Castle Bridge and Forebay, 1973-2012

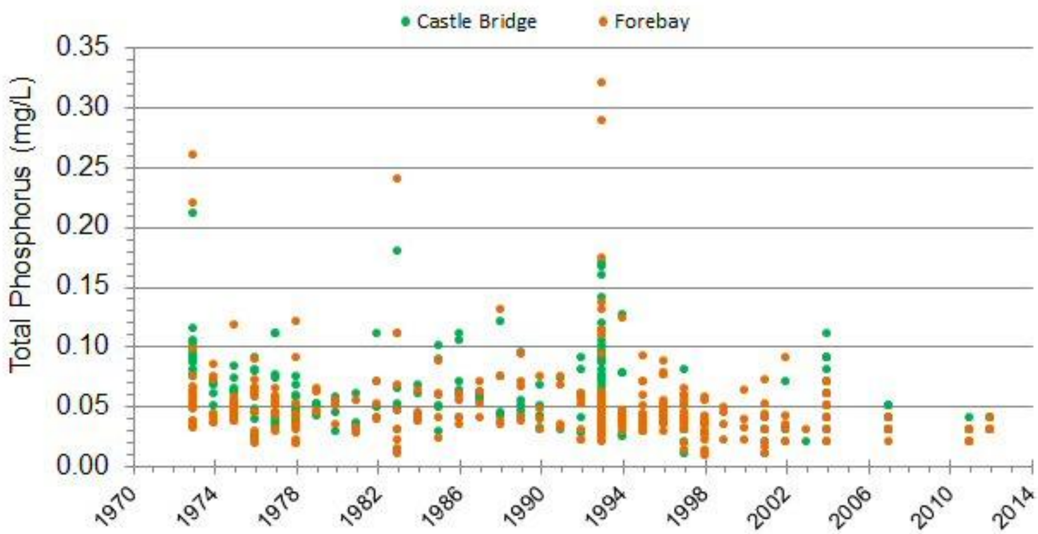


Figure 10C. Total Phosphorus Concentrations Measured at the Forebay and Tailrace, 1973-2014.

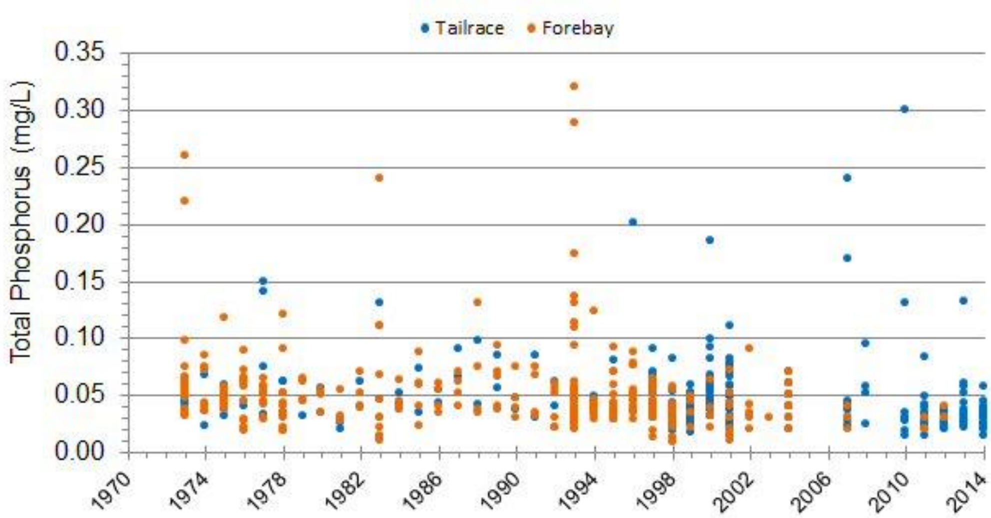


Figure 11A. Nitrate-Nitrogen in the Euphotic Zone, Rhodhiss Lake, 1993.

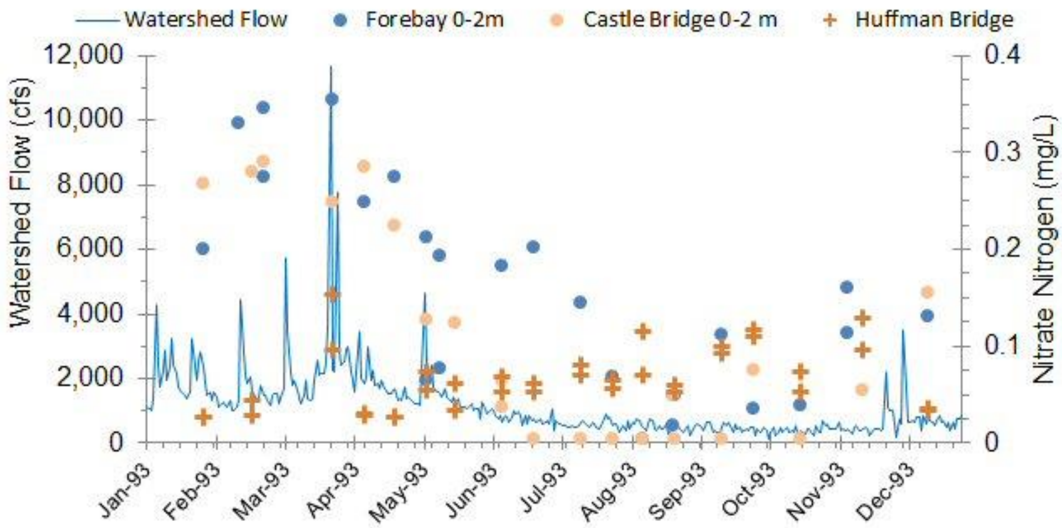


Figure 11B. Kjelhahl-Nitrogen in the Euphotic Zone, Rhodhiss Lake, 1993.

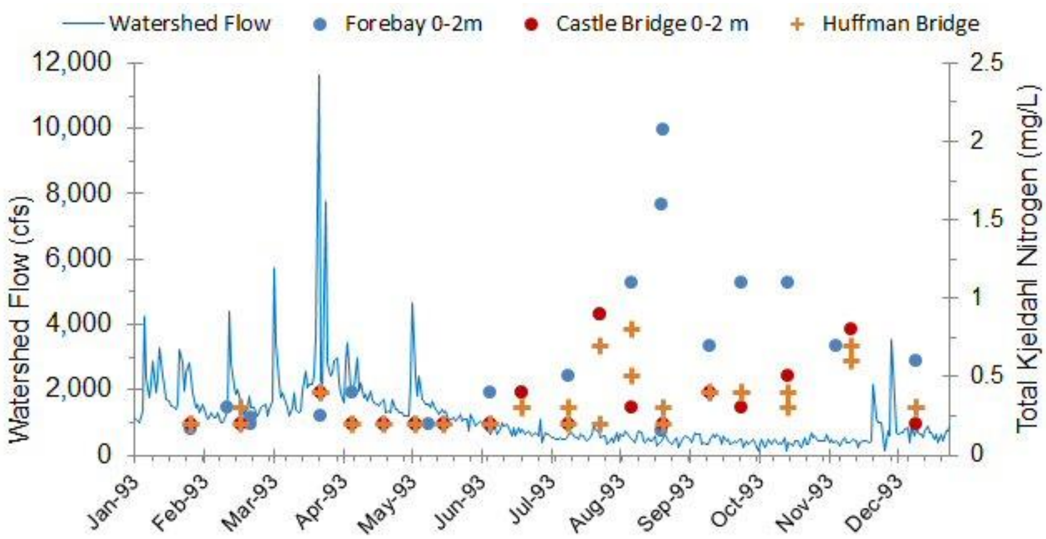


Figure 11C. Total Phosphorus in the Euphotic Zone, Rhodhiss Lake, 1993

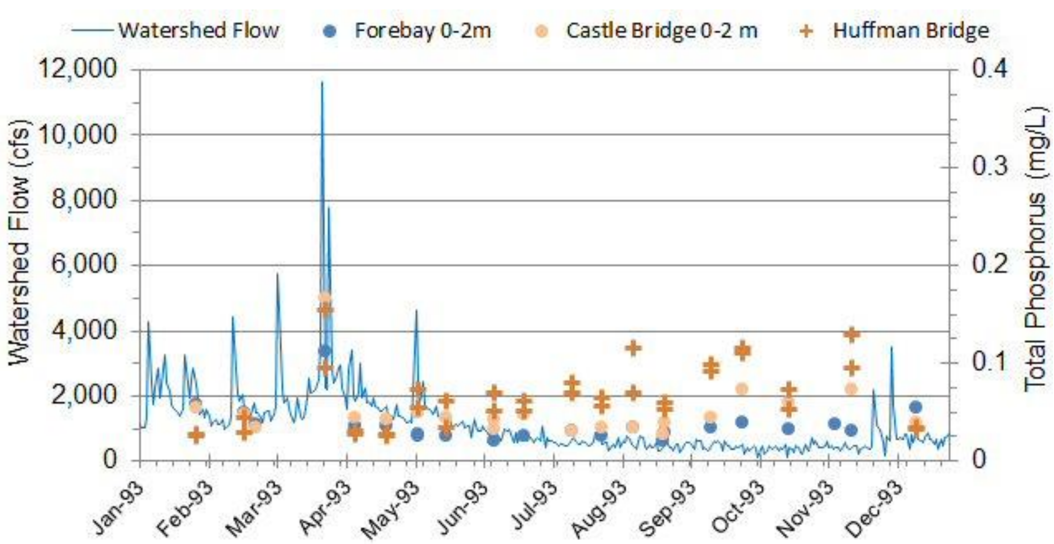


Figure 12A. Nitrate-Nitrogen in the Deeper Water, Rhodhiss Lake, 1993.

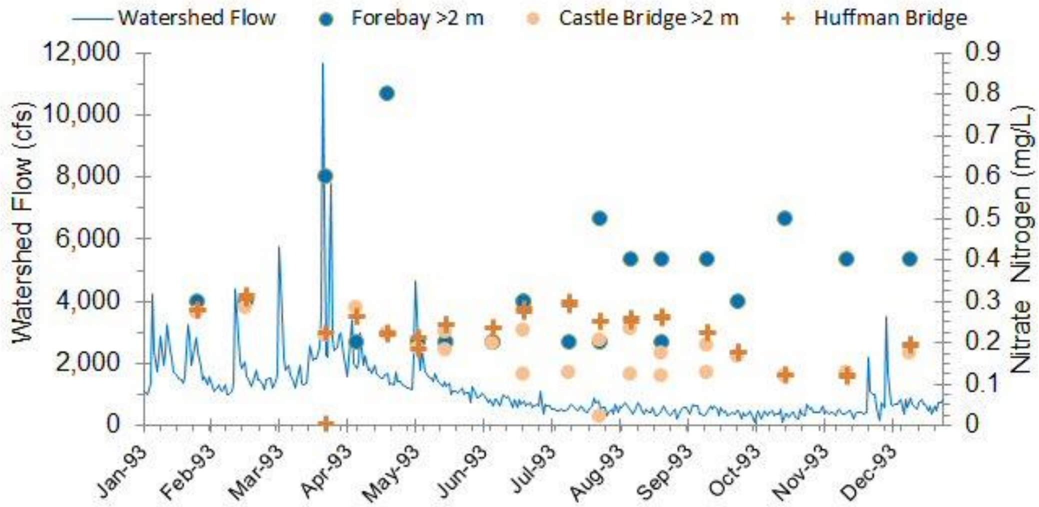


Figure 12B. Kjelhahl-Nitrogen in the Deeper Water, Rhodhiss Lake, 1993.

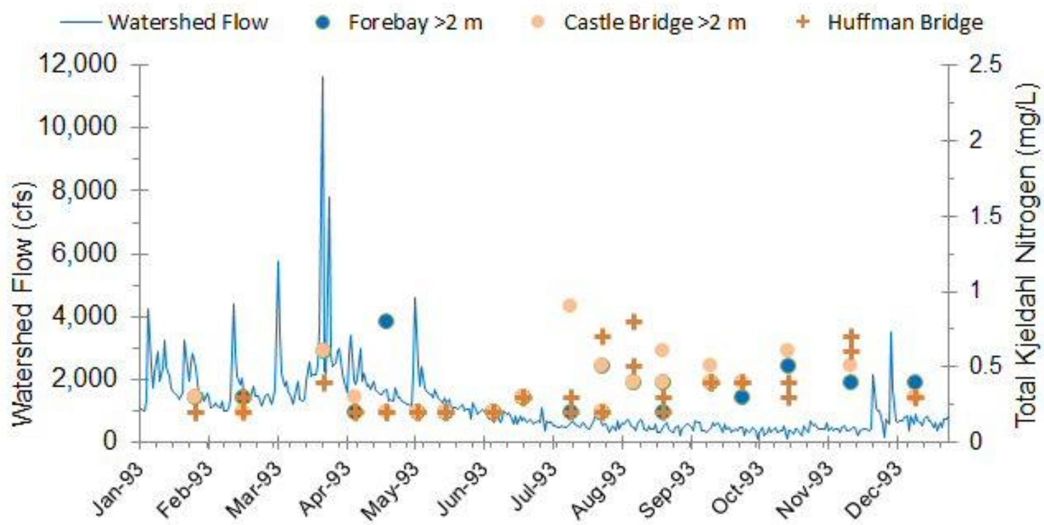
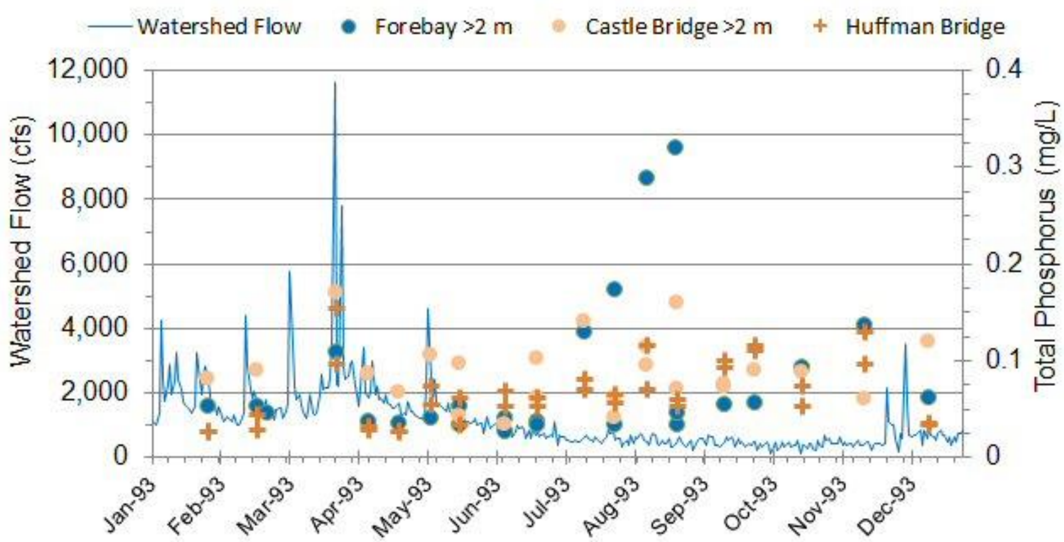


Figure 12C. Total Phosphorus in the Deeper Water, Rhodhiss Lake, 1993



Elemental stoichiometries of the seston and plankton can reflect the type and extent of nutrient limitation. In addition, the ratios of the elemental nutrients loaded into the lake often reflect the composition of the plankton (Wetzel, 2001). Progressively higher nitrogen to phosphorus ratios (N:P) (Figure 13A and B) greater than 23 reflects greater phosphorus limitation to phytoplankton. Reservoirs with short retention times typically have N:P ratios greater than 26. The seasonal N:P ratios in the euphotic zone (Figure 13A) suggest severe summer phosphorus demand as the plankton moves towards the forebay. Lower N:P ratios in the deeper depths reflect the increased phosphorus from settling phytoplankton, particulate material, or deep Valdese discharge. Little phosphorus from the inflowing rivers or the Valdese WWTP discharge reaches or remains in the surface euphotic zone. Based upon the N: P ratios observed at the upper reservoir locations, the nitrogen and phosphorus stoichiometries reflect the inflowing water nutrient ratios. These ratios reflect potential nitrogen limitation. Based upon the Algal Growth Potential Test reported by the NCDENR (2013), Rhodhiss waters were nitrogen limited. However, during the summer months as the water approaches the forebay, the plankton became severely phosphorus limited forcing the natural phytoplankton to rely on high re-cycling rates of phosphorus to sustain growth and production rates. Wetzel (2001) points out that the naturally growing algae may have similar growth rates as used for culture samples, but, due to high turnover rates of phosphorus by the natural plankton the similar growth rates occurred at much lower phosphorus concentration than the cultured samples.

The depressed forebay chlorophyll concentrations reflect the phosphorus depletion and limitation. Under these conditions, algal populations actually increased in the fall reflecting the high euphotic zone turnover rates of phosphorus. Wetzel (2001) points out that the actual mass of phosphorus has relatively little influence on algal growth rates, rather the rate of re-cycling and cellular storage of phosphorus by the algae heavily influence algal growth rates. However, as algae settle out of the euphotic zone or lost through the outfall, the rate of phosphorus loading into the reservoir controls productivity, not the standing crop. The availability of combined nitrogen and phosphorus intermittently limit photosynthesis, but in reservoirs, particularly those with high non-algal turbidity, available light in the euphotic zone pose a greater limitation to algal productivity. Application of Carlson's (2001) criteria for nutrient and non-nutrient limitations (Table 6), Rhodhiss' primary production limitation was primarily light due to suspended clays.

Table 6. Causes for Deviation from Biomass-Based Trophic State Index (after Carlson, 1992)

Rhodhiss Location	Seech Disc Depth [1] (m)	TSI(SD)	Chlorophyll[1] (ug/L)	TSI(CHL)	Total Phosphorus[1] (ug/L)	TSI(TP)	TSI(CHL)-TSI(TP)	TSI(CHL)-TSI(SD)
Huffman Bridge	0.6	67.4	2.0	37.5	56	62.2	-24.6	-29.8
Castle Bridge	1	60.0	14.3	56.7	43	58.4	-1.7	-3.3
Forebay	1.2	57.4	10.4	53.6	37	56.2	-2.6	-3.8
	Causes of Deviation from Trophic State Index (TSI) Carlson (1992)							
	TSI(CHL)-TSI(TP) greater than 0				P limitation		Large Particles	
	TSI(CHL)-TSI(TP) less than 0				Clay Turbidity		Non-P limitation	
			TSI(CHL)-TSI(SD)		less than 0		greater than 0	

[1] From Table 3

Figure 13A. Nitrogen to Phosphorus Ratios and Chlorophyll in the Euphotic Zone, Rhodhiss Lake, 1993.

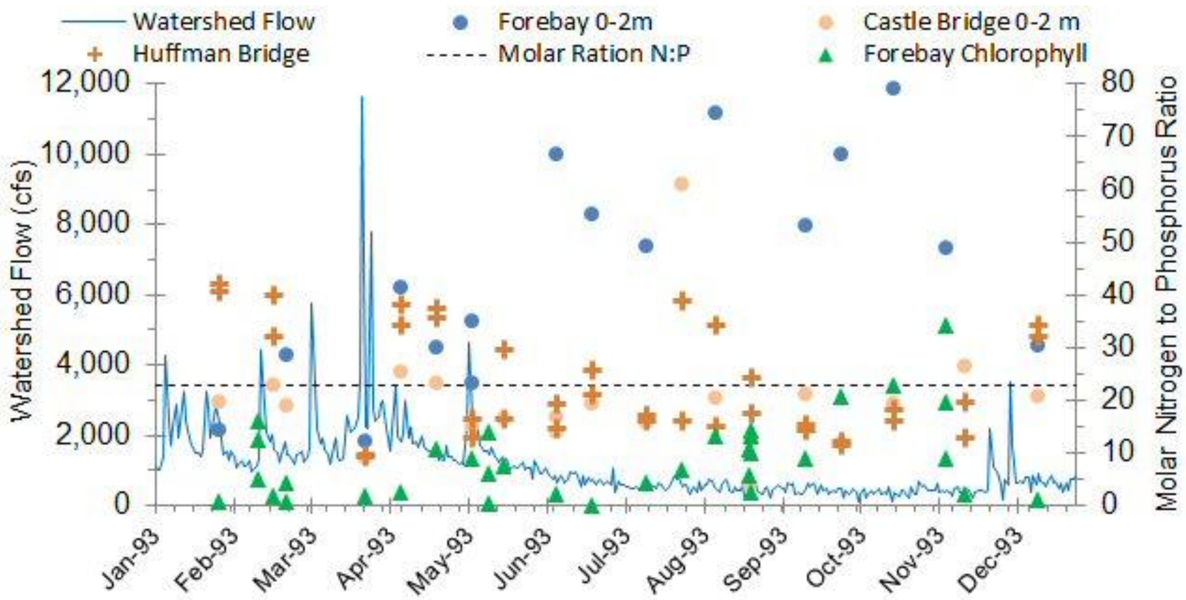
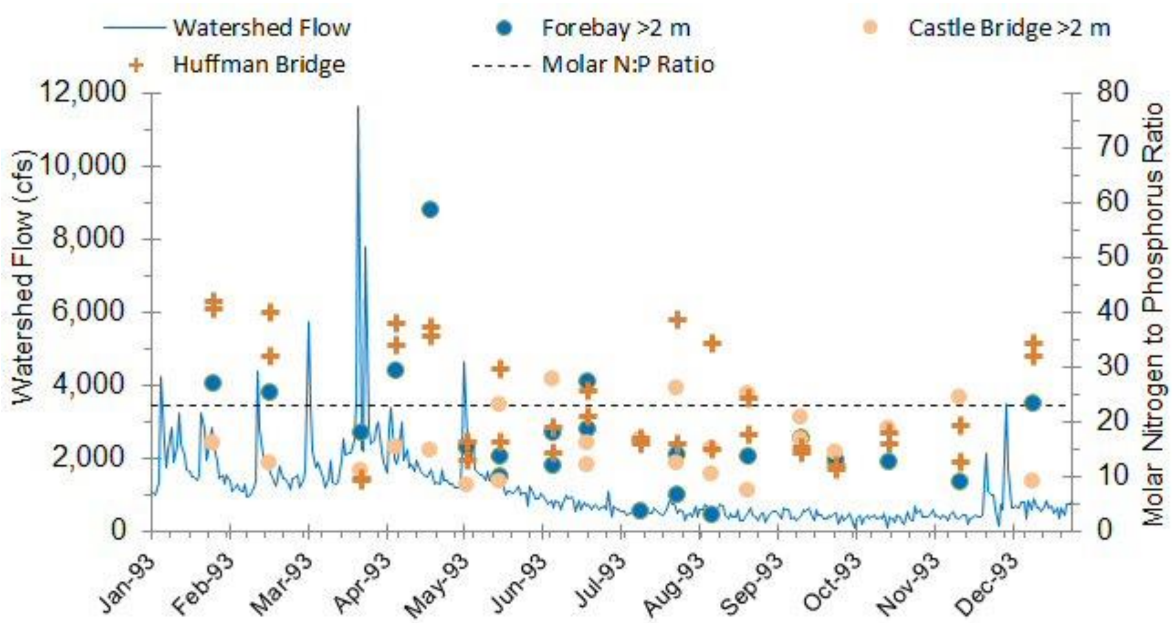


Figure 13B. Nitrogen to Phosphorus Ratios in the Deeper Water, Rhodhiss Lake, 1993.



Trends of nutrient concentrations were analyzed as was the yearly differences for pH and O_2. The frequency of occurrence of total nitrogen concentrations indicated reduced concentrations at the Castle Bridge site over the years, especially from 2005 to 2014 (Figure 14A). Concentration differences of total nitrogen were less pronounced at the forebay site. Typically maximum total nitrogen concentrations were observed prior to 2005 at both sites. Forebay total nitrogen concentrations were highly variable between the years; the releases downstream showed the highest concentrations (Figure 14B). Most of the nitrogen measurements were made from surface waters where nitrogen metabolism was highly variable (see previous section). This was in contrast to the tailwater samples which represented the withdrawal of the entire water column, including the bottom water. All of the highly variable nitrogen concentrations were a function of varying loading rates, varying seston settling rates, decomposition rates, de-nitrification rates, and nitrogen fixation rates at different times and locations throughout the years.

The frequency distribution of phosphorus concentrations generally exhibited lower values in more recent years, especially at the forebay location. All of the sampled locations had the highest phosphorus concentrations during the 1973-2001 period. Generally the Castle Bridge site exhibited higher phosphate levels than the forebay due to the settling of phosphate particulates. However, as phosphate concentrations decreased through the years, differences between the Castle Bridge site and the forebay were less pronounced. As with nitrogen, most of the data used for the exceedence plots came from samples which were collected in the surface water (usually less than 2 meters). The tailrace samples showed a consistent trend of lowered phosphate concentrations in Lake Rhodhiss through the years. As was discussed above, many processes, namely loading and subsequent transport and settling of particulates, influence the distribution of phosphorus. Since the tailrace samples represent an integration of the entire water column due to Rhodhiss' withdrawal zone, the tailrace samples provided a complete representation of the total reservoir phosphorus dynamics.

Figure 14A Frequency of Occurrence of Total Nitrogen Concentrations, Forebay and Castle Bridge Sites, 1973-2012.

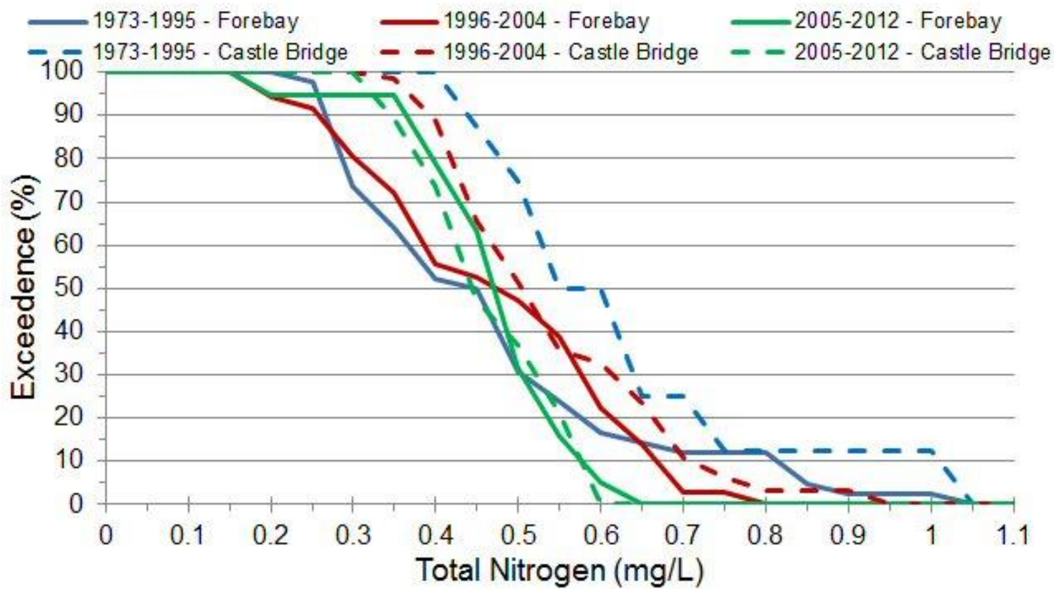


Figure 14B. Frequency of Occurrence of Total Nitrogen Concentrations, Forebay and Tailrace Sites, 1973-2014.

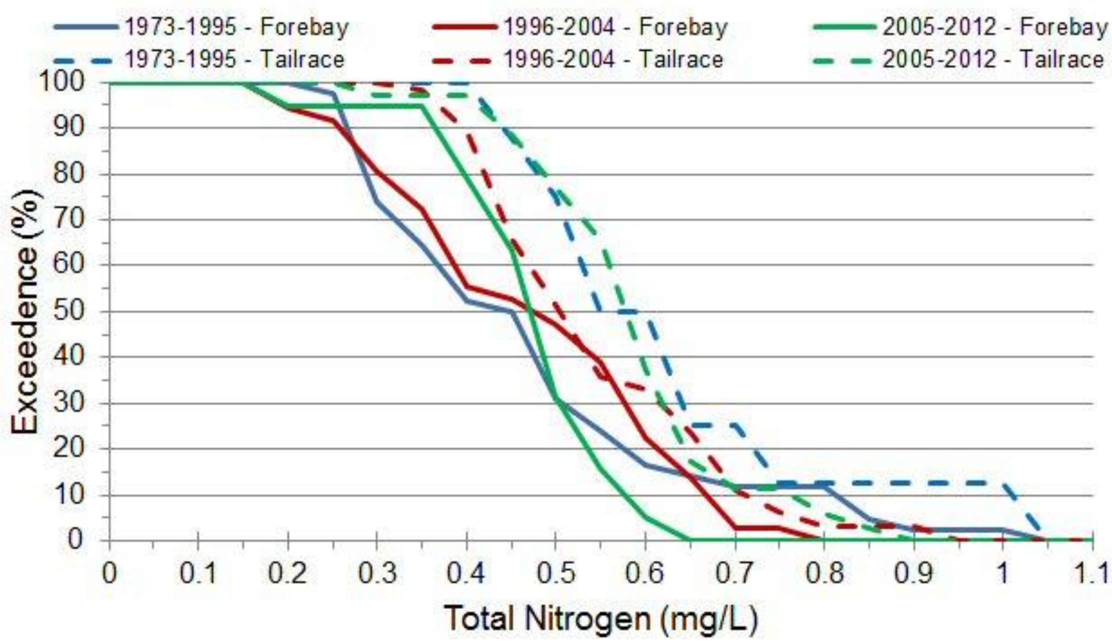


Figure 15A. Frequency of Occurrence of Total Phosphorus Concentrations, Forebay and Castle Bridge Sites, 1973-2012.

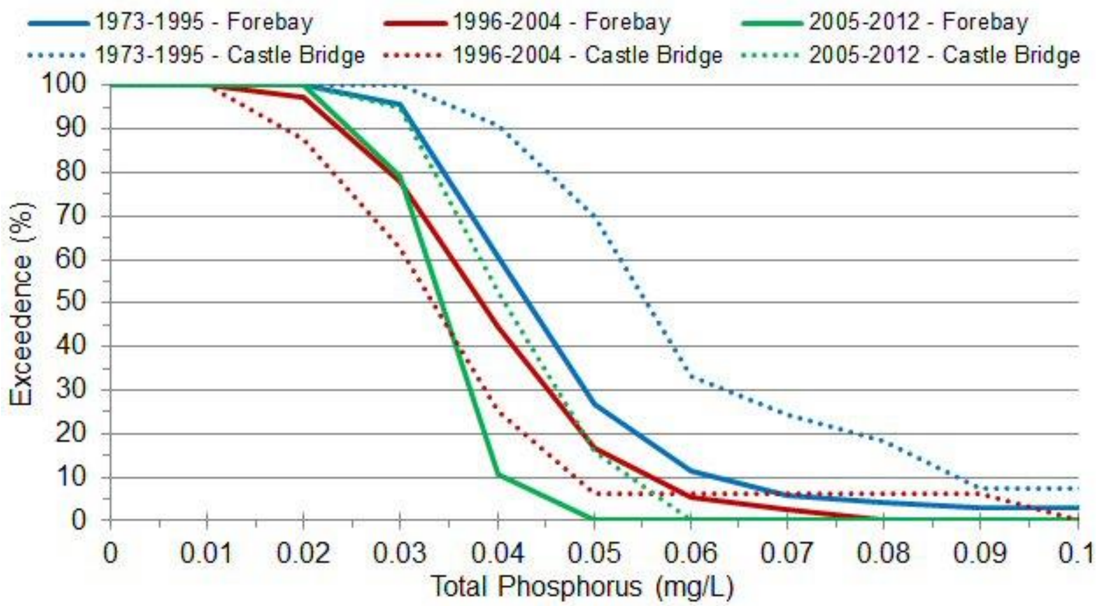
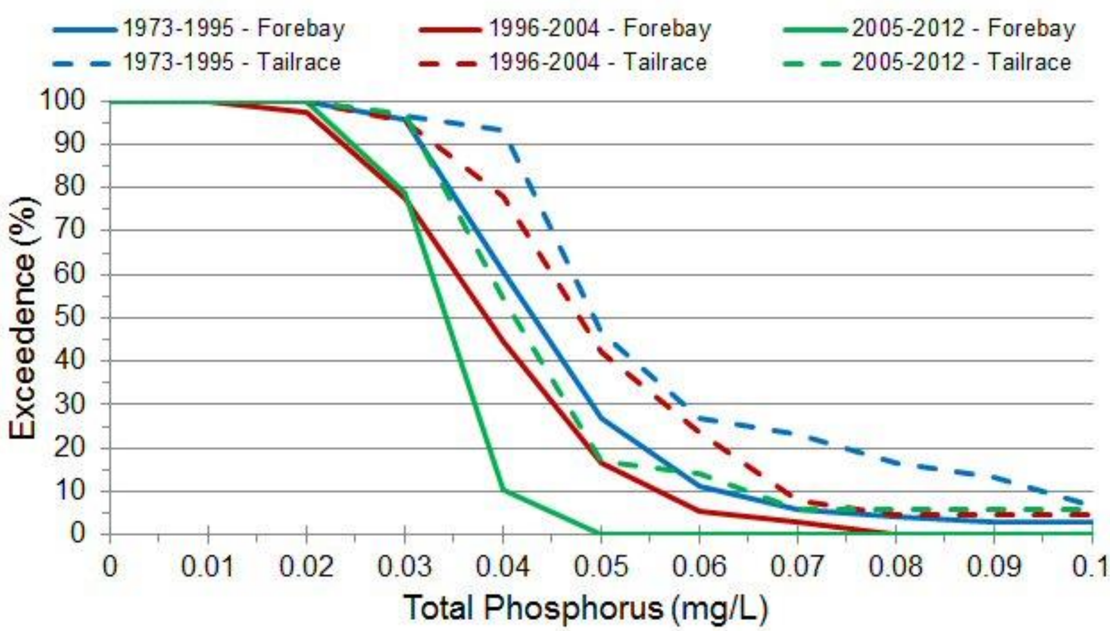


Figure 15B. Frequency of Occurrence of Total Phosphorus Concentrations, Forebay and Tailrace Sites, 1973-2014.



3.5 <u>Nitrogen and Phosphorus Loading</u>

3.5.1 WWTP, Bridgewater, and Local Watershed Nutrient Loading

The phosphorus loading to Lake Rhodhiss from the three WWTP discharges (Figures 16A) showed a significant reduction since the late 1990's. The Valdese WWTP exhibited significant reductions throughout the entire period. The Morganton WWTP had periodic reductions followed by peak loadings. The Lenoir plant had consistent low levels of phosphorus loading. As mentioned previously, the addition of phosphorus by the Morganton and Lenoir facilities were somewhat mitigated by the suspended material in the receiving streams. Reduced lake phosphorus concentrations were primarily the result of decreased phosphorus loading by the Valdese WWTP.

Nitrogen loadings to the lake were somewhat consistent throughout the period, with periodic pulses primarily from the Morganton WWTP. Valdese's nitrogen loading decreased slightly over the years, but not near as significant as the phosphorus reduction. Lenoir continued to contribute low amounts of nitrogen to the lake.

Figure 16A. Phosphorus Monthly Loading Rates into Lake Rhodhiss from WWTP Point Sources, 1997-2014

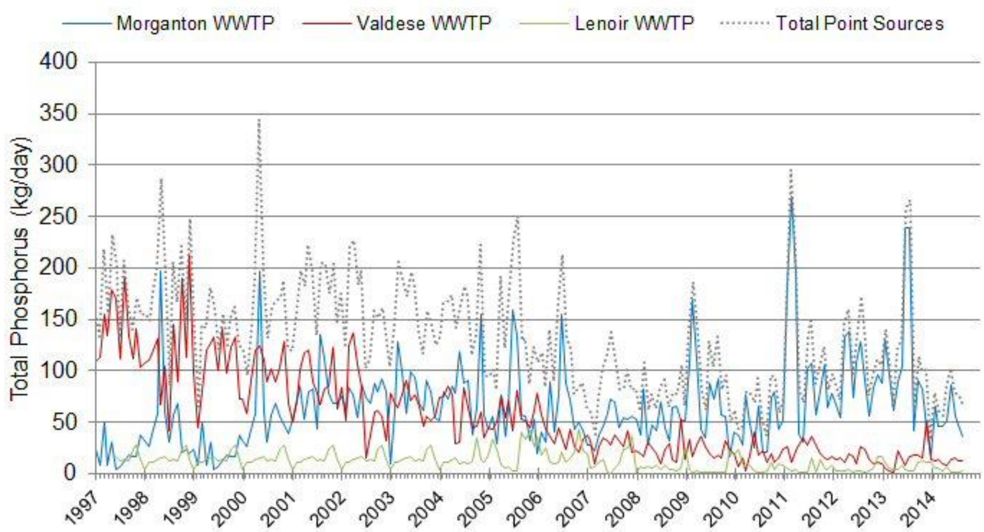


Figure 16B. Nitrogen Monthly Loading Rates into Lake Rhodhiss WWTP Point Sources, 1997-2014

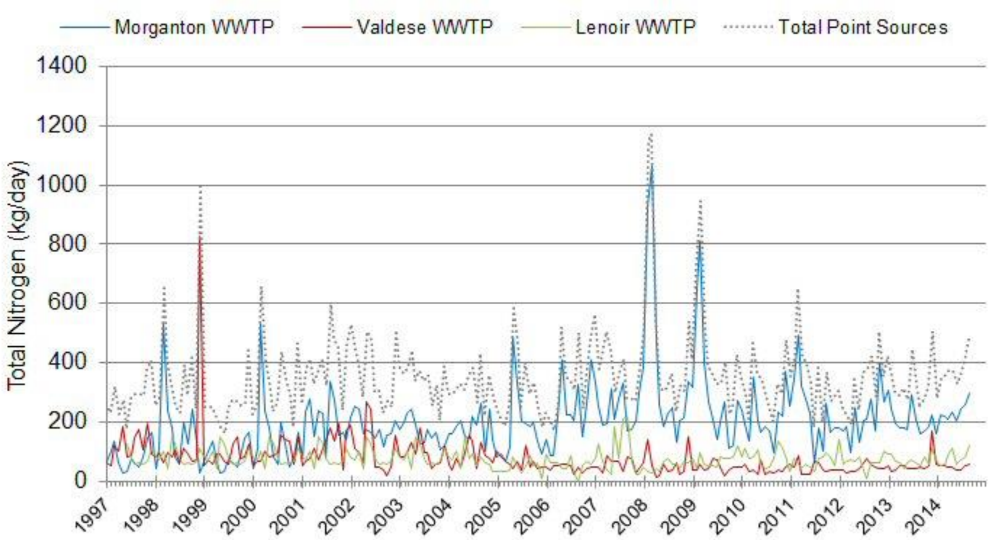


Figure 17A. Comparison of Phosphorus Loading Rates from Major Sources into Lake Rhodhiss, 1997-2014

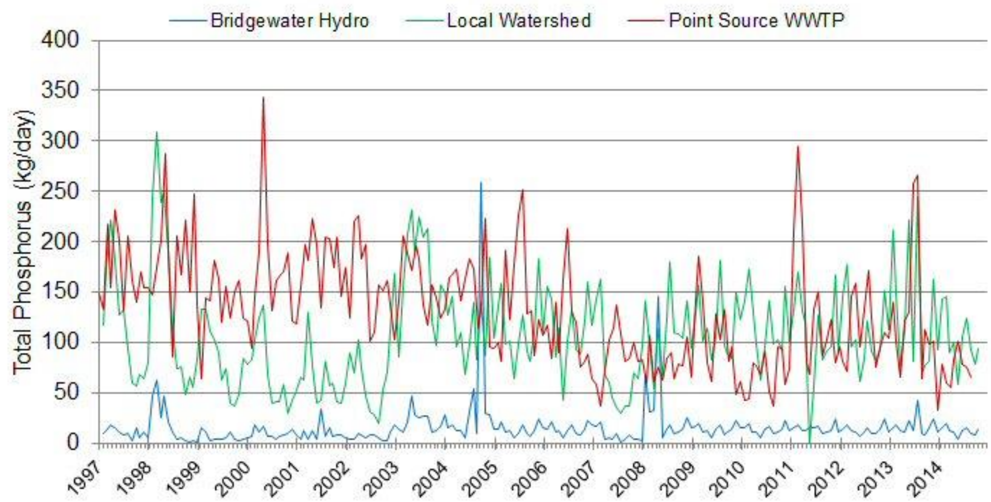
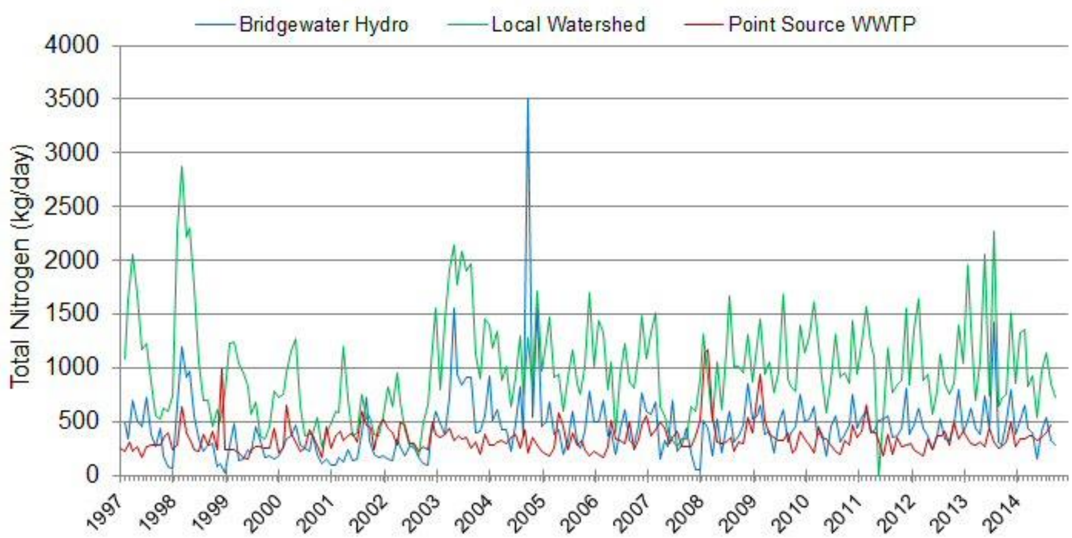


Figure 17B. Comparison of Nitrogen Loading Rates from Major Sources into Lake Rhodhiss, 1997-2014



With the exception of the 2004 flooding originating from Hurricane Francis, water released from Bridgewater hydro contributed very low levels of phosphorus downstream to Lake Rhodhiss. From 1997 to 2003 most of the phosphorus load originated from the WWTP facilities (Figure 17A). Since that time, phosphorus loadings were approximately equal from point and non-point sources, with periodic peak loadings from either source.

Nitrogen loadings, on the other hand, primarily originated from the local watershed (Figure 17B) throughout the years[6]. Most of the nitrogen originating from the watershed was nitrate-N rather than particulates measured as TKN.

The dramatic reduction of phosphorus loading to Rhodhiss was revealed by the frequency of occurrence plots of the loading rates (Figure 18A). Little differences were observed from the phosphorus originating from the local watershed, but very significant phosphorus reductions from the WWTP plants had occurred since 2005. Most of this reduction was attributed to the Valdese facility which discharged directly into Lake Rhodhiss. Nitrogen sources changed little from 1997 to 2014 (Figure 18B).

[6] As with phosphorus, the Francis flood in 2004, caused the greatest nitrogen loading to the lake

Figure 18A. Frequency of Occurrence of WWTP and Local Watershed Total Phosphorus Loading Rates, 1997-2014

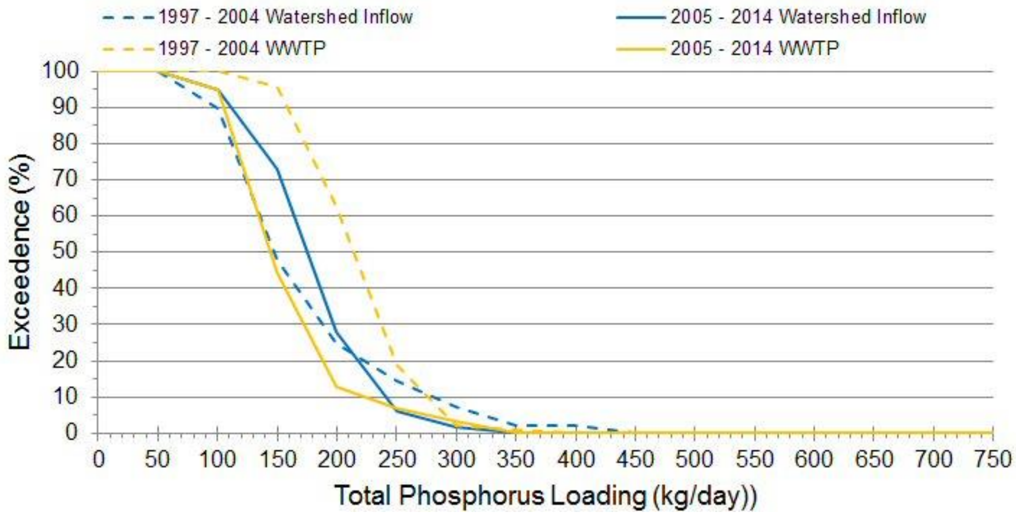
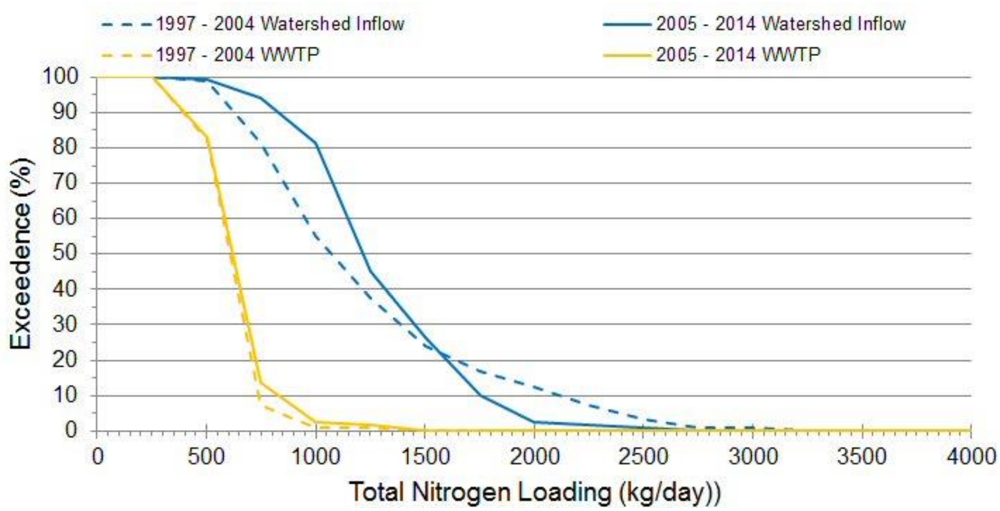


Figure 18B. Frequency of Occurrence of WWTP and Local Watershed Total Nitrogen Loading Rates, 1997-2014



3.5.2 Lake Rhodhiss Nutrient Release to Lake Hickory

In the previous sections, the loss of phosphorus throughout the lake was discussed as a function of particulate loading, settling to the deeper depths or sediments by either organic or inorganic particulates, or retention times. The net result of these processes was demonstrated by comparing the total phosphorus loading to the total phosphorus export from the Rhodhiss hydroelectric facility (Figure 19A). Throughout the entire time from 1997 to 2014 phosphorus was continually released downstream, but always less than the total lake loading. These data indicate that phosphorus was lost to the sediments and not released or re-suspended to the water column. Internal phosphorus loading to Lake Rhodhiss was non-existent or insignificant.

Conversely, total nitrogen inputs to Lake Rhodhiss were approximately equal to the amount of nitrogen released downstream. Again, as previously discussed, the multitude of activities of varying loading rates, varying seston settling rates, decomposition rates, de-nitrification rates, and nitrogen fixation rates all contributed to sources and sinks of nitrogen. But the overall metabolism of nitrogen resulted in no net gain or loss of nitrogen from Lake Rhodhiss.

Figure 19A. Comparison of Phosphorus Loading Rates Reservoir Releases, 1997-2014

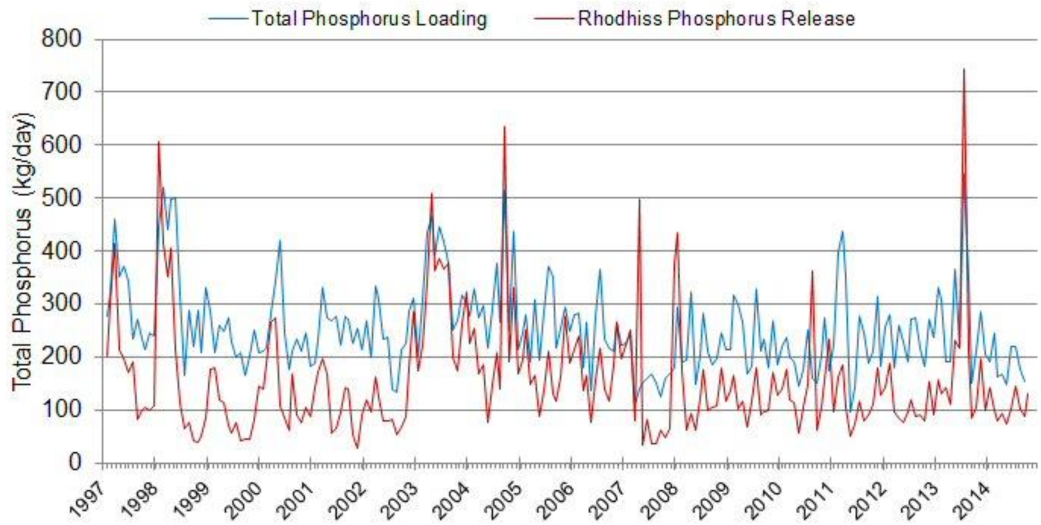
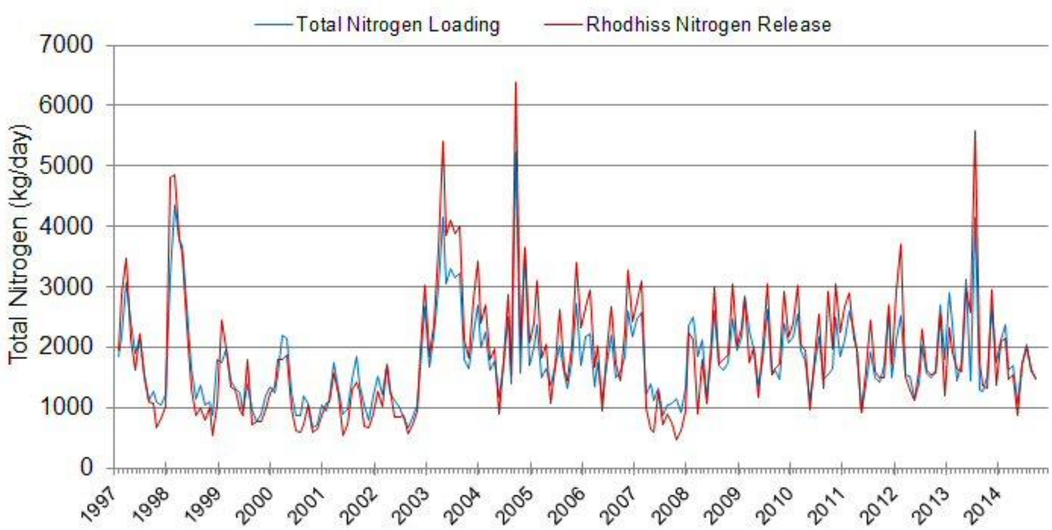


Figure 19B. Comparison of Nitrogen Loading Rates Reservoir Releases, 1997-2014



The period from 2005 to 2014 exhibited lower phosphate loading rates to Lake Rhodhiss than the previous eight years (Figure 20A). This reduction of phosphorus loading to the lake was proportional to the reduction of phosphorus in the water released to Lake Hickory. In other words, Lake Rhodhiss retained phosphorus in proportion to the external loading.

Nitrogen exhibited just the opposite trend as phosphorus. Namely, from 2005-2014, slightly more nitrogen was added to the lake than in the 1997-2004. Concurrently, the same increase of nitrogen into the lake was reflected in the amount of nitrogen released downstream. These data indicate that, unlike phosphorus, that some of the nitrogen released downstream was derived in the lake, either by nitrogen fixation or interaction with the sediments.

Figure 20A. Frequency of Occurrence of Total Phosphorus Rates of Inflow and Outflow, 1997-2014.

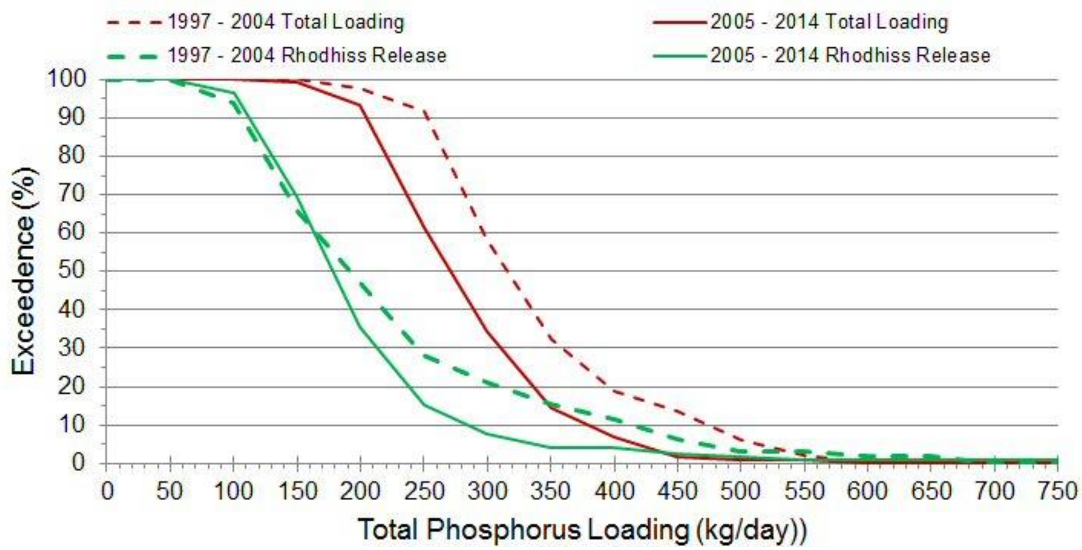
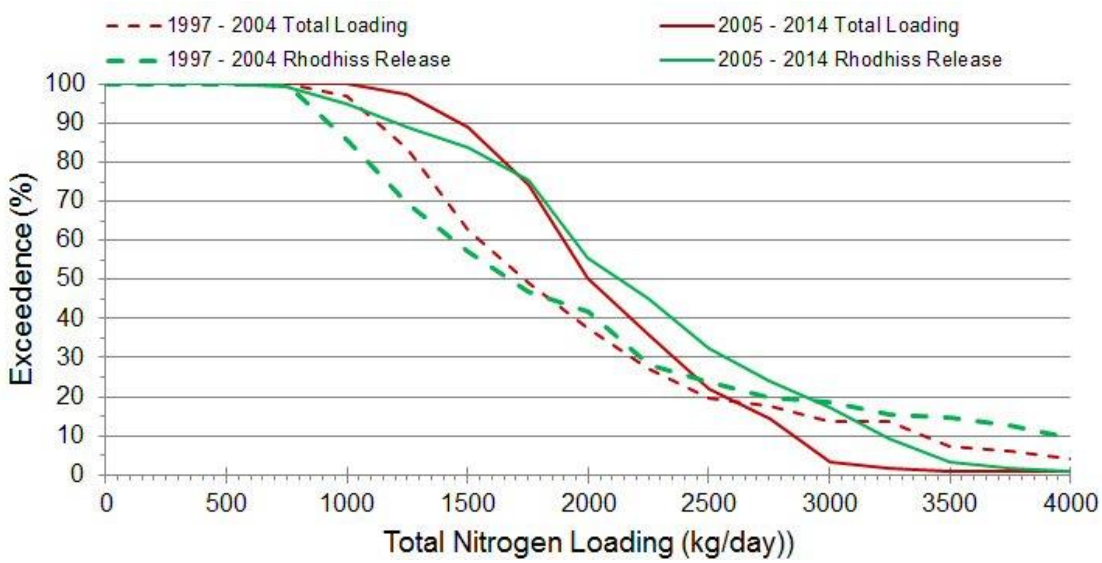


Figure 20B. Frequency of Occurrence of Total Nitrogen Rates of Inflow and Outflow, 1997-2014.



3.5.3 Lake Rhodhiss Nutrient Loading Summary

During the period of 1997-2004, point source phosphorus loading to Rhodhiss Lake was 60% of the total loading. This percentage was reduced to 43% by 2005-2014. The non-point source phosphorus loading increased by 18% between 1997 and 2014; whereas the total phosphorus loading to Lake Rhodhiss also decreased by 18%. These reduced phosphorus loads were due to a 75% phosphorus reduction from the Valdese WWTP and a 48% reduction from the Lenoir WWTP facility (Table 5). Bridgewater Hydro contributed only 11% of the phosphorus load throughout the years. Rhodhiss Lake released 53% and 55% of the inflowing phosphorus to Lake Hickory from 1997-2004 and 2005-2014, respectively.

Approximately 20% of the total nitrogen input to the lake originated from the WWTP facilities. The non-point source nitrogen increased by 20% between 1997 and 2014. The total nitrogen loading to Lake Rhodhiss also increased by 20%. While Valdese reduced nitrogen input by 48%, the Morganton WWTP increased nitrogen loads 44% between the years (Table 5). Bridgewater Hydro contributed 30% of the nitrogen throughout the years. Rhodhiss Lake released 92% of the inflowing nitrogen to Lake Hickory from 1997-2004. However, the 2005-2014 period, 7% more nitrogen was released downstream than was added to the lake by all of the point or non-point sources.

Phosphorus or nitrogen loading rates and subsequent nutrient concentrations within a reservoir were typically used to define the trophic status of waterbodies (Wetzel, 2001). However, the importance of these nutrients assumes that phosphorus, and to some degree nitrogen, was a limiting factor effecting pelagic algal[7] communities. The trophic status of a reservoir, even though defined by many parameters, refers to the productivity and growth of limnetic algal communities. Yearly or summer mean chlorophyll concentrations and/or summer chlorophyll maxima have typically been used as surrogates[8] for primary production when applied to nutrient loading models. Based upon many of these models, Lake Rhodhiss should be extremely eutrophic (very high chlorophyll concentrations) since its phosphorus loading rate was 5.4 gm/m^2/yr and nitrogen loading was 43.7 gm/m^2/yr. These values were 27 times and 15 times higher, respectively, than the permissible levels of nutrient loading described by Wetzel (2001). Clearly, these models do not apply to Lake Rhodhiss and/or the plankton community was limited by other factors[9]. NCDENR has consistently used (from 1982 - 2013) pH and percent oxygen saturation as measures of water degradation and impairment[10]. But, as previously discussed, these parameters were indicators of phytoplankton production and growth, not necessarily measures of algal populations (standing crop) or specifically, nuisance algal concentrations.

[7] Nutrient loading may also effect macrophyte growth and distribution, by since Lake Rhodhiss has very little, if any, littoral macrophyte populations, the algal populations discussed refers to the phytoplankton in Lake Rhodhiss
[8] Chlorophyll concentrations are actually another measure of algal standing crop as are phytoplankton densities
[9] For example, refer to Table 6
[10] High pH and DO saturation resulting from high algal productivity rarely impairs other aquatic life or human use

Table 5. Net Nutrient Balance for Lake Rhodhiss, 1997–2014.

Total Phosphorus Loading Statistics										
		Outflow	Inflow	Non-Point Source			Point Source			
		Rhodhiss Release to Lake Hickory (kg/day)	Total Loading (kg/day)	Total Non-Point Loading (kg/day)	Bridgewater (kg/day)	Local Watershed (kg/day)	Total WWTP Loading (kg/day)	Valdese WWTP (kg/day)	Morganton WWTP (kg/day)	Lenoir WWTP (kg/day)
1997 - 2004										
	minimum	31	136	26	2	20	65	15	3	4
	maximum	636	522	400	260	310	344	214	197	35
	mean	175	286	121	17	105	165	93	58	15
	median	144	270	94	11	86	162	89	57	13
2005 - 2014										
	minimum	34	97	16	1	0	33	2	17	0
	maximum	744	547	289	147	246	295	81	269	42
	mean	147	232	126	16	110	106	26	71	9
	median	121	219	116	14	102	94	22	57	5
Total Nitrogen Loading Statistics										
		Outflow	Inflow	Non-Point Source			Point Source			
		Rhodhiss Release to Lake Hickory (kg/day)	Total Loading (kg/day)	Total Non-Point Loading (kg/day)	Bridgewater (kg/day)	Local Watershed (kg/day)	Total WWTP Loading (kg/day)	Valdese WWTP (kg/day)	Morganton WWTP (kg/day)	Lenoir WWTP (kg/day)
1997 - 2004										
	minimum	551	675	366	36	185	165	17	26	31
	maximum	6400	5236	4803	3506	2873	1003	828	532	149
	mean	1796	1746	1407	437	970	339	107	152	81
	median	1348	1466	1147	339	794	312	90	146	71
2005 - 2014										
	minimum	480	877	508	63	4	174	12	62	0
	maximum	5577	4154	3707	1431	2276	1172	171	1065	218
	mean	1971	1855	1487	465	1022	368	51	247	70
	median	1883	1752	1376	446	950	343	47	209	66

4. BIOLOGICAL DATA

4.1 Phytoplankton

4.1.1 General Phytoplankton Trends

The phytoplankton data available for this report was sampled quarterly between 1993 through 2000 (Duke Energy, John Derwort, personal communication). Total algal densities[11] exhibited very consistent yearly periodicity, e.g. low levels during the winter and typically higher levels in the spring and summer with numbers decreasing in the fall (Figure 21). Only in 1995 did algal populations reach the NCDENR (2013) level of a "mild bloom". The phytoplankton levels did not appear to be limited by the total phosphorus or the water retention time. Phosphorus concentrations undoubtedly influenced the species dominance since, very rarely, did phosphorus concentrations decrease below 20 цg P/L. Rhodhiss' conditions favored algal species which had optimum growth rates and phosphorus tolerances greater than 20 цg P/L[12].

The autotrophic phytoplankton in Lake Rhodhiss exhibited a diverse assemblage of nearly all taxonomic groups typically found in temperate lakes. The taxonomic diversity as well as the specific population levels (algal densities) was a response to specific requirements for light, temperature, nutrients (macro and micro), buoyancy regulation, competition, productivity, generation times, and predation. Generally, within the same waterbody, the seasonal periodicity of the phytoplankton biomass remains fairly constant, with maxima and minima density and biomass typically out of phase with rates of productivity. Primary productivity usually follows the annual cycle of solar radiation and the resultant seasonal temperatures. The total amount of phytoplankton in Lake Rhodhiss followed this pattern described by Wetzel (2001).

Algae are extremely diverse with a wide tolerance to changing environmental conditions found in the open water. Algal populations exhibit co-existence of many species, but usually, either spatially or temporally, the phytoplankton are usually dominated by one or two species in association with many rarer forms. Rhodhiss phytoplankton followed this pattern.

Phytoplankton possesses two major responses to changing environmental conditions. The first type of adaptive response requires cell growth and division (generation times) e.g. specific niche requirements, species competition, species size, etc. The second algal adaptive feature is control over metabolic processes e.g. types and levels of photosynthetic pigments, buoyancy control, carbon metabolism, rapid enzymatic dynamics, etc. within cells (shorter than generation intervals) (Harris, 1978). The specific population dynamics of the phytoplankton in Lake Rhodhiss cannot be ascertained with samples collected three months apart. But rather, various assemblages of algae may share certain characteristics which provide inference as to major controlling factors.

The size distribution[13] of the Lake Rhodhiss plankton community (Figure 22) revealed that most of the algae (≈ 80% of the density) were less than 20 цm[14]. The ultraplankton were characterized as having (1) high metabolic rates with high efficient nutrient uptake, (2) high nutrient recycling rates, (3) generation times in hours rather than days, (4) little loss due to sedimentation or predation, and, (5) population densities were determined by internal metabolic dynamics rather than external nutrient inputs (Wetzel, 2001). Communities dominated by small cells typically exhibit greater productivity per unit algal biomass than larger cells (as discussed previously, high pH and DO levels were indicators of high productivity).

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[11] See NCDENR (2013) for definition

[12] Wetzel (2001) grouped algae as follows: optimum growth and tolerance less than 20цg/l, optimum growth less than 20 цg/l but tolerances greater than 20 цg/L, and optimum growth and tolerance greater than 20 цg/L

[13] The size of individuals within a species was calculated by dividing the total species biovolume by the density of that species to yield $цm^3$ per unit counted. For a simple assumption, the radius of a sphere was calculated from the resultant volume. The calculated radius was used as the species size.

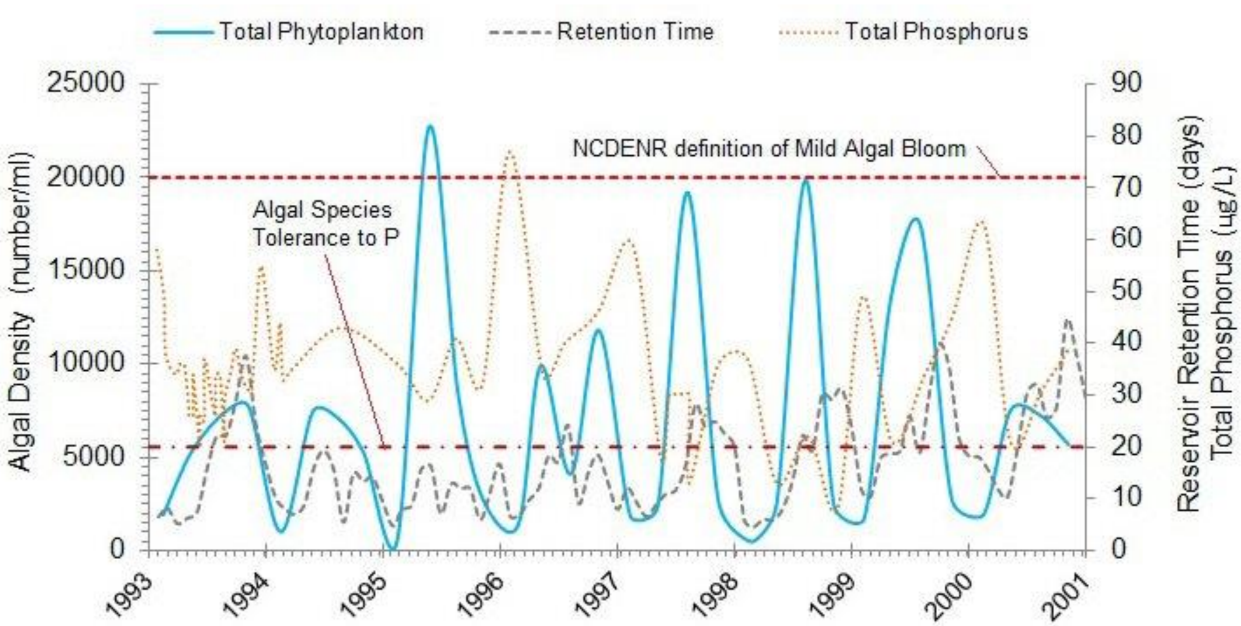
[14] Algae less than 20 цm are called ultraplankton, algae greater than 20 цm are classified as microplankton

Based upon the previous discussion on lake stratification (high pH and O_2, chlorophyll levels, advective flow, phosphorus and nitrogen relationships), the phytoplankton in Lake Rhodhiss exhibited both adaptive features to take advantage of the changing characteristics of the lake. What cannot be addressed adequately by quarterly sampling only in the forebay was whether phytoplankton size decreased downstream as a result of predation or settling[15].

All forms of algae were susceptible to macro turbulence, influencing the available light or nutrients available to the algae. But under a stable water column (low vertical mixing), some algae have adapted to adjust their depth (either by buoyancy control or mobile forms with flagella). The primary factor influencing this adaptive strategy was to optimize light levels for photosynthesis. A secondary benefit of depth regulation was increased nutrient uptake at deeper depths. Forms exhibiting depth regulation were present in Lake Rhodhiss throughout the years, but greatly increased in August (Figure 22) probably due to increased water column stability. Species of cyanobacteria (blue-green algae) and chrysophyceae (golden-brown algae) (Figure 25) were the dominate forms capable of depth regulation. Additionally, small numbers of euglenophyceae (euglenoids) and dinophyceae (dinoflagellates) were also present.

The ability to convert atmospheric nitrogen (N_2) to available nitrogen (primarily as NH_3) was an adaption of some forms of cyanobacteria. Nitrogen fixation rates usually increased during times of nitrogen deficiencies indicated by low molar N:P ratios (less than 23) (Wetzel,2001 and Smith, 1983). The total density of species of cyanobacteria capable of nitrogen fixation (identified by Issa, et.al., 2014) (Figure 24) revealed that highest number of nitrogen fixers were observed every August. However, only in 1995, when N:P ratios were low (nitrogen limiting) did they reach significant population levels (≈ 13000 units per ml). Only in 1997 and 1998, and possibly 1994 did algae capable of nitrogen fixation remain low at high N:P ratios (phosphorus limiting). The remaining years showed little relationship to N:P ratios.

Figure 21. Total Algal Density (units/ml) of Lake Rhodhiss Forebay, 1993-2000
..



[15] Larger algae are more susceptible to predation, especially by filter feeding fish, and exhibit increased settling rates

Figure 22. Size Distribution of Lake Rhodhiss Forebay Phytoplankton, 1993-2000.

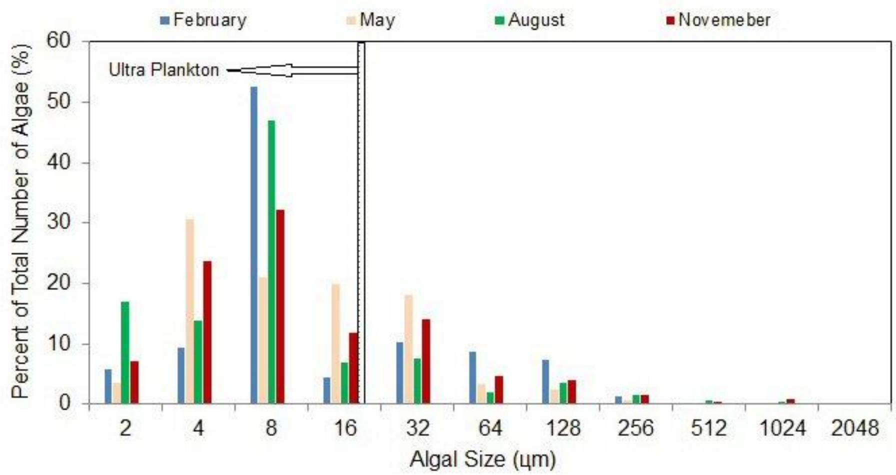


Figure 23 Total Algal Density (cell/ml) Compared to those Algae Capable of Depth Regulation vs. Total Phosphorus Concentrations of Lake Rhodhiss Forebay, 1993-2000

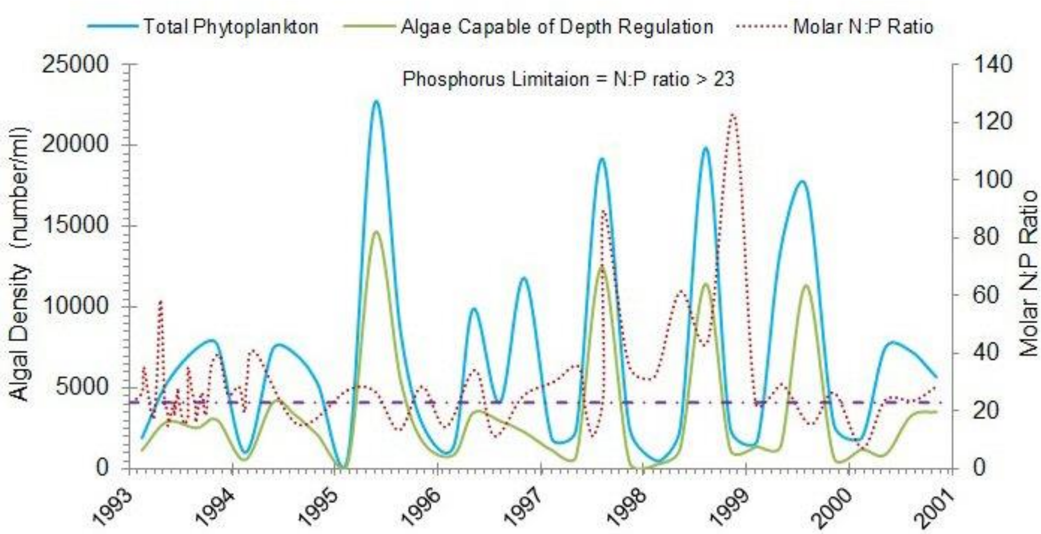
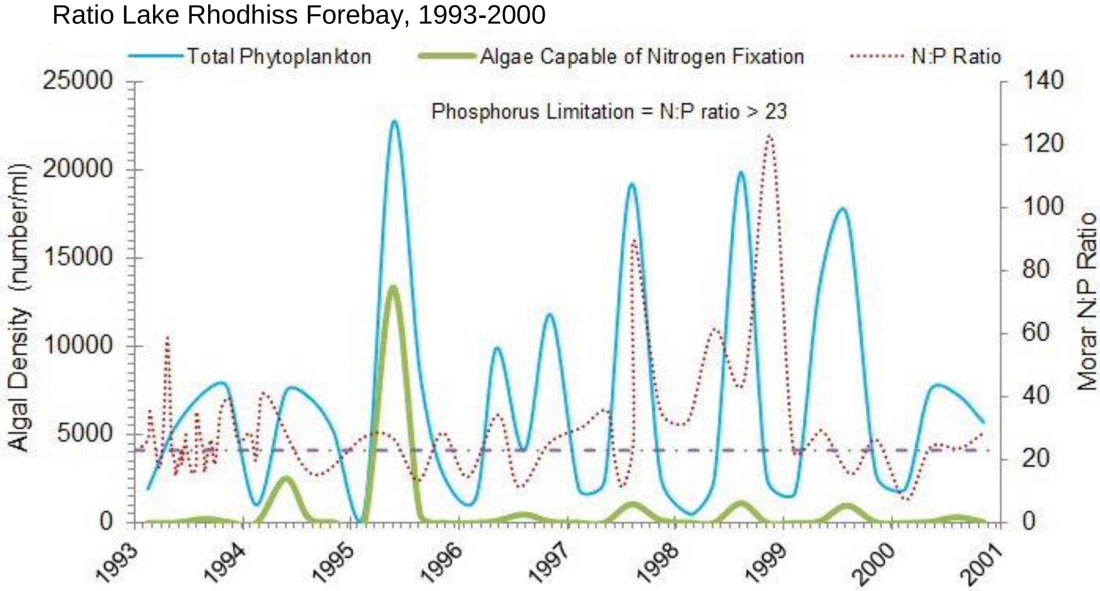


Figure 24 Total Algal Density (cell/ml) Compared to those Algae Capable of Nitrogen Fixation vs. N:P Ratio Lake Rhodhiss Forebay, 1993-2000



4.1.2 Seasonal Succession of Major Phytoplankton Species

The seasonal succession of the types of phytoplankton (classes)[16] (Figures 25 and 28) was similar each year with blue-green algae peaking in August concurrent with the golden-brown algae. In 1996 and 2000, the golden-brown algae peaked in May, prior to the blue-green maxima. However, each year exhibited a different species assemblage within each class of algae.

In 1996, when phosphorus levels were fairly high, Oscillatoria[17] reached ≈13000 units per ml, however, in 1995 when phosphorus levels were about equal to 1996, all species of the cyanobacteria were low. In 1997 and 1998 when phosphorus levels were lowest, Lyngbya dominated. Chroococcus was present in fairly low concentrations in most of the spring-summer samples. Even though Cylindrospermopsis were present in low numbers prior to 1999, it dominated the cyanobacteria in that year but did not reach high numbers.

The chrysophyceae (golden-brown algae) were represented by three major species (Figure 27). Many of the chrysophyceae were described as phagotrophic (consume bacteria), especially Ochromonas. Synura typically has high phosphorus requirements and prefers cooler water. In Lake Rhodhiss, its only appreciable numbers occurred in February, 1994. Erkenia subaequiciliata dominated the chrysophyceae community each year. Little is known of its ecology, but has been reported to prefer cool water but may occur any time of year (Kozak et.al., 2014). In Rhodhiss reservoir, this species was co-dominant with the cyanobacteria in August.

Ever present, the bacillariophyceae (diatoms) peaked in the spring of 1995 and 1999 and in the fall-winter of 1996 (Figure 28). Skeletonema potamos dominated the diatoms in 1995 and 1996 and was a co-dominate diatom with Cyclotella meneghiniana in 1999 (Figure 29). Diatoms usually had a cool water preference and typically dominated the plankton during the fall-winter mixing period (especially Melosira) and during the spring warming period when turbulent mixing kept them exposed to sunlight the euphotic zone. As the water warmed in spring, the larger forms settled out of the euphotic zone. However, not every year were diatoms in abundance, again illustrating the highly variable nature of Lake Rhodhiss.

The small chlorophyceae (green algae), represented primarily by ankistrodesmus, chlamydomonas, and unidentified coccoid greens, were always present in very low numbers (Figure 30) and never dominated the plankton community. The small, flagellated cryptophyceae (primarily Rhodomonas minuta with some Cryptomonas ovata) were ever present in Lake Rhodhiss (Figure 31). Even though these ubiquitous algae were found in most freshwater, regardless of the trophic state, little is known of their ecology (Wetzel, 2001).

[16] The species chosen for the graphics represented species which had achieved significant levels throughout the 8 year period, or were present in the majority of the samples.

[17] Species underlined in the plots were listed as potential species which, at high numbers, could cause taste and odor problems, see next section.

Figure 25 Cyanobacteria (Blue-green Algae) and Chrysophyceae (Golden-Brown Algae) Density (units/ml) of Lake Rhodhiss Forebay, 1993-2000

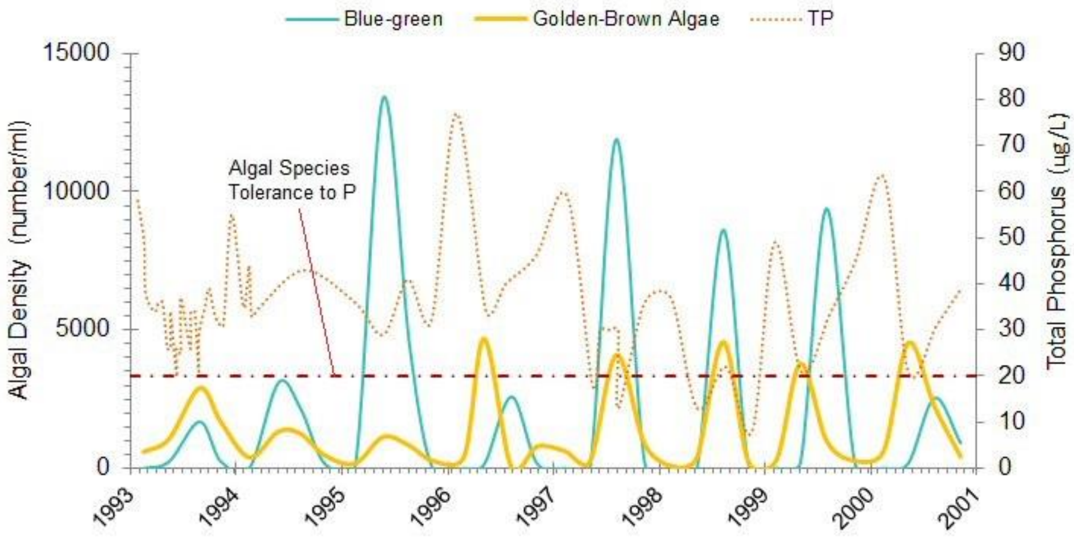


Figure 26. Dominant Species of Cyanobacteria, Lake Rhodhiss Forebay, 1993-2000.

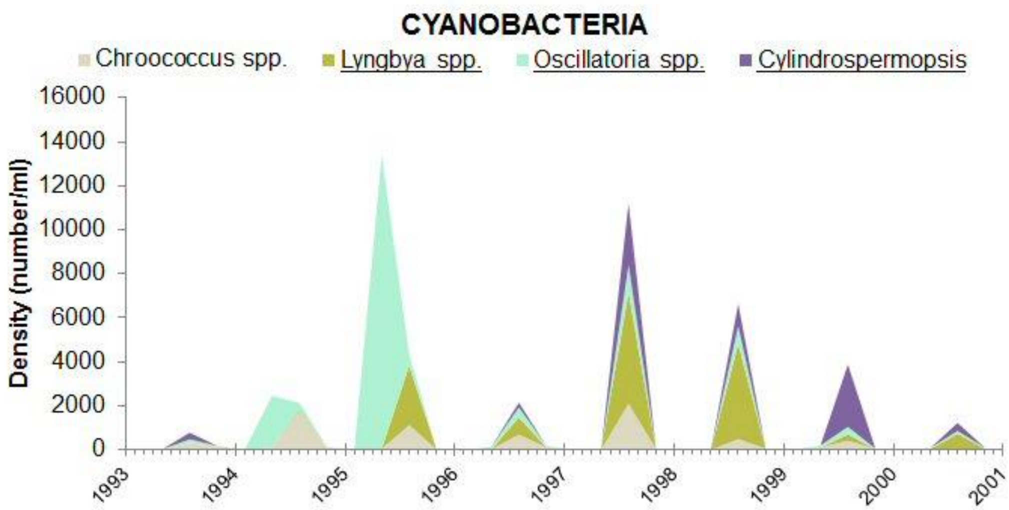


Figure 27. Dominant Species of Chrysophyceae (golden-brown algae), Lake Rhodhiss Forebay, 1993-2000.

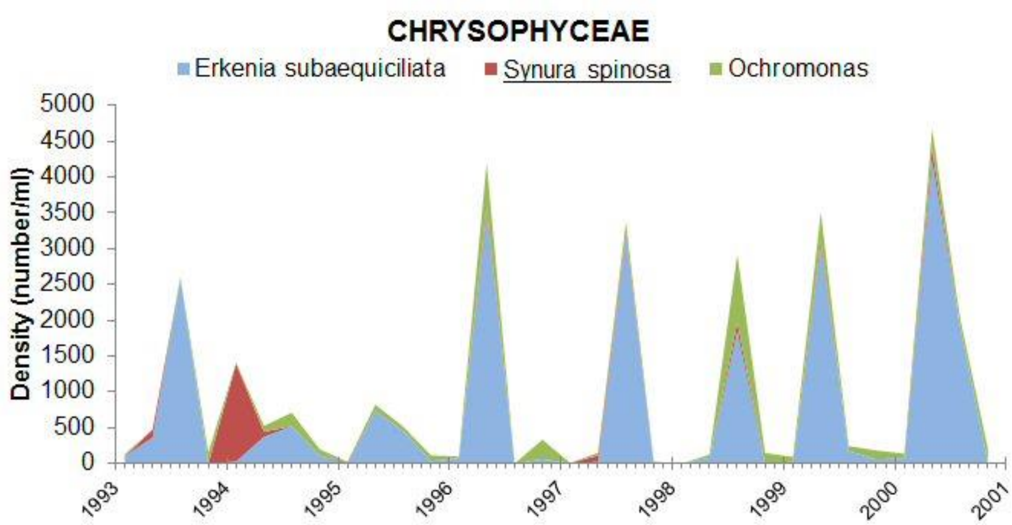


Figure 28 Bacillariophyceae (Diatoms) and Chlorophyceae (Green Algae) Density (units/ml) of Lake Rhodhiss Forebay, 1993-2000

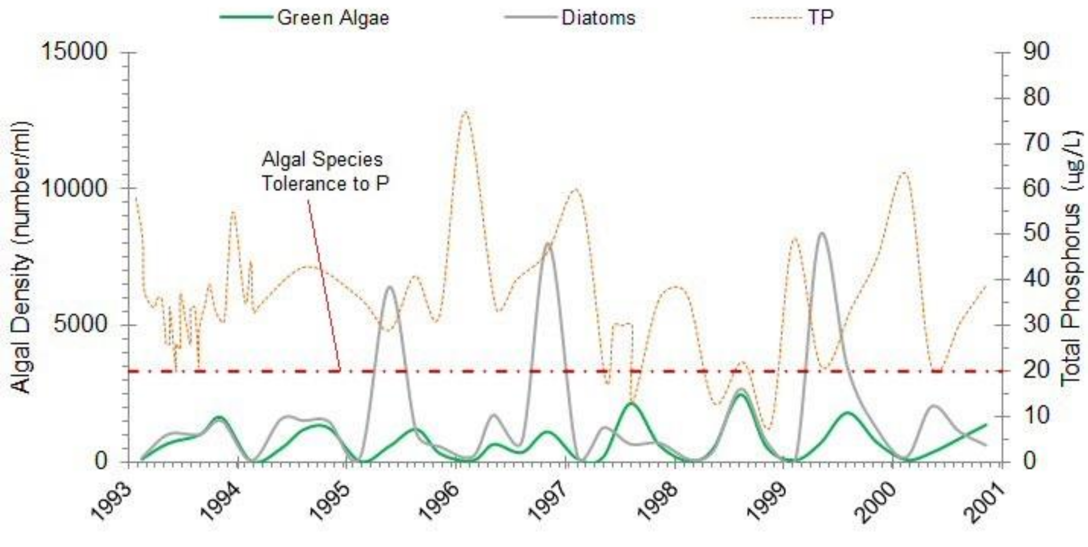


Figure 29. Dominant Species of Bacillariophyceae (Diatoms), Lake Rhodhiss Forebay, 1993-2000.

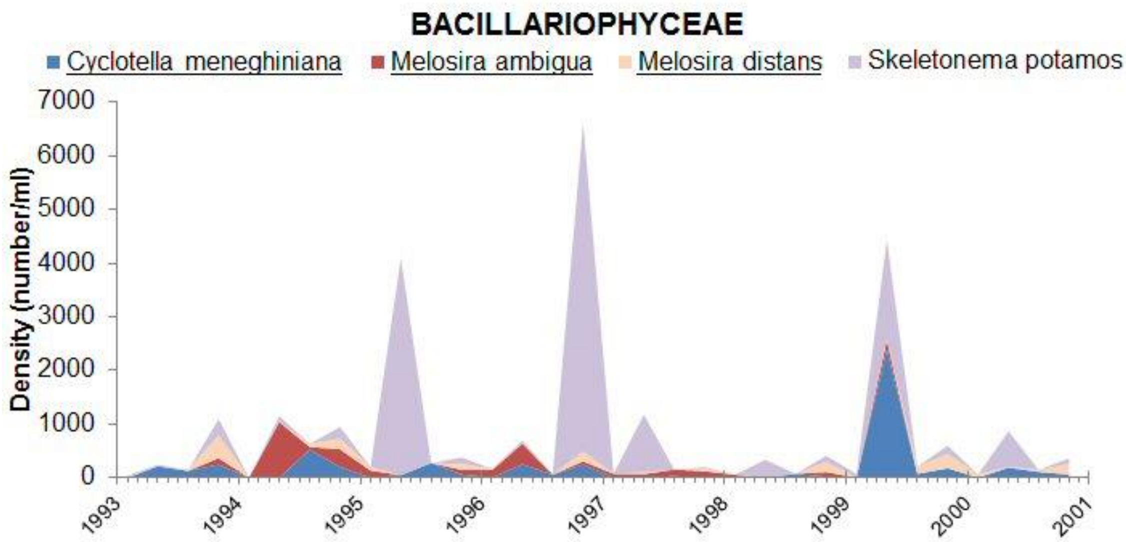


Figure 30. Dominant Species of Chlorophyceae (Green Algae), Lake Rhodhiss Forebay, 1993-2000.

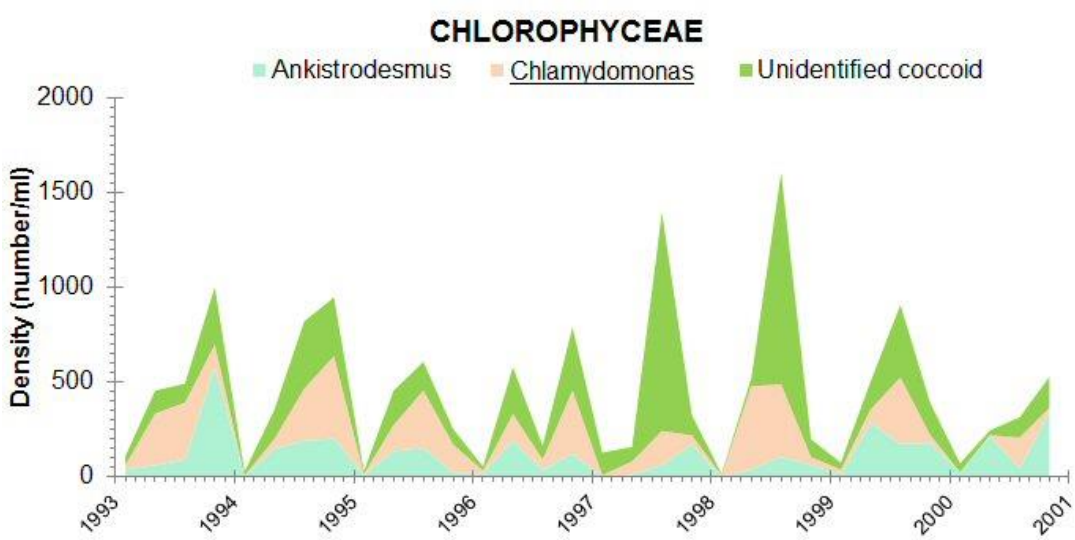
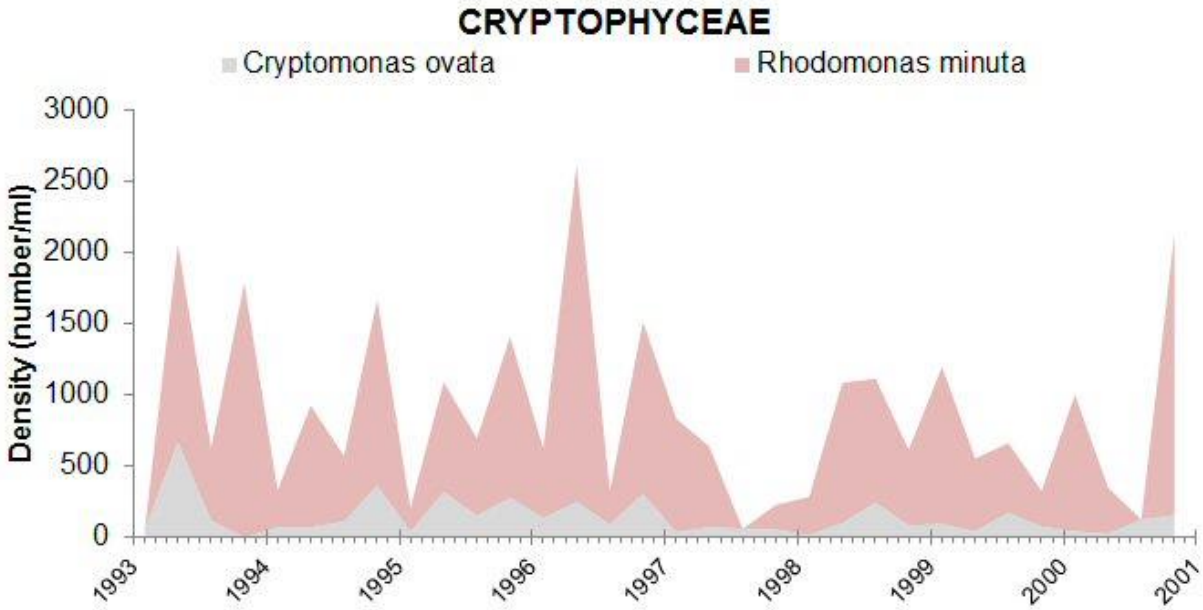


Figure 31. Dominant Species of Cryptophyceae (Cryptomonads), Lake Rhodhiss Forebay, 1993-2000.



4.1.3 Taste and Odor Causing Algae

During the 1999-2002 low flow years (Figure 5), both Valdese and Lenoir experienced taste and odor problems in their potable water supply. Granite Falls did not report taste and odor problems with their potable water supply (see Figure 2 for intake locations). The species found in Lake Rhodhiss known to have caused taste and odor problems in North American drinking water supplies (Wagner, 2016) were quite numerous (Table 6). Most of the taxa were relatively rare in Rhodhiss, but, Oscillatoria and Lyngbya exhibited the highest populations during the 8 year period.

The algal populations, especially Oscillatoria and Lyngbya, were low in 1999 and 2000 (Figure 26). However, Granite Falls intake (located in the Lake Rhodhiss forebay) and did not report any taste and odor problems. The Lenoir and Valdese water supply intakes were located in the vicinity of Castle Bridge (approximately 5 miles upstream) where taste and odor in the water supply required additional treatment. Under low inflow conditions, the algal populations (presumably a cyanophyta species) appear to have bloomed upstream but dissipated by the time the water reached the forebay. Additionally, the bloom causing the taste and odor problem was of short duration and the sampling in August failed to sample it.

Table 6. Potential Lake Rhodhiss Algal Taxon to Cause Taste and Odor Problems (after Wagner, 2016)

TAXON	Maximum Observed Density (#/ml)
CHLOROPHYCEAE	
Chlamydomonas	440
Closterium	18
Cosmarium	140
Dictyosphaerium	64
Lagerheimia	121
Oocystis	36
Pediastrum	35
Scenedesmus	314
Schroederia	6
BACILLARIOPHYCEAE	
Asterionella	137
Cyclotella	2399
Melosira	1038
Nitzschia	2912
Stephanodiscus	728
Synedra	349
Tabellaria	18
CHRYSOPHYCEAE	
Chrysosphaerella	419
Dinobryon	349
Mallomonas	73
Synura	1366
Uroglenopsis	672
DINOPHYCEAE	
Ceratium	35
Peridinium	576
Dinoflagellate spp.	152
EUGLENOPHYCEAE	
Euglena	30
Phacus	30
Trachelomonas	30
CYANOBACTERIA	
Anabaena	152
Anabaenopsis	559
Lyngbya	4155
Oscillatoria	7649
Cylindrospermopsis	2829

4.2 Fisheries

Threadfin shad (*Dorosoma petenense)* and Gizzard Shad (*Dorosoma cepedianum)* were the major forage fish in all of the Catawba-Wateree reservoirs and were a major source of food of all game fish. Both species feed extensively on plankton by filtering water with gill rakers, and have been known to drive changes in the planktonic populations. As mentioned previously, extensive feeding by these fish typically will drive plankton to smaller sizes as they consume the larger forms. Threadfin shad were principally open water feeders (limnetic) whereas Gizzard shad were both pelagic and littoral feeders. Unlike Gizzard shad, threadfin shad have a low temperature tolerance, and typically die around 6° C. Both species are highly prolific with up to 20000 eggs per threadfin female and 400,000 eggs per gizzard shad female (SCDNR, 2016).

On the average, Lake Rhodhiss had high populations of limnetic forage fish (Table 7), only Lake Hickory and Wateree had higher populations. The higher densities of forage fish (number/ha) indicated not only the high productivity of the system but also the potential to significantly alter the planktonic community structure.

In all of the Catawba reservoirs, not only did the populations of the forage fish vary greatly from year to year, but the relative abundance of threadfin and gizzard shad varied significantly (Tables 7 and 8). These variations were probably related to the winter water temperatures where threadfin die offs happen below 6° C, but stocking[18], spawning rates, survival of larval and young fish, predation, as well as variations in lake productivity probably influenced forage fish numbers and relative abundance.

In addition to similar forage fish densities, composition, and fluctuations between the Catawba-Wateree reservoirs, the composition and standing stocks of other fish species in Lake Rhodhiss were also comparable to the other reservoirs (Duke Energy, 2007, Tables E3.1-9, E3.1-10, and E3.1-11). These similarities indicate that the fish populations in Lake Rhodhiss were subjected to environmental variations experienced by other reservoirs and were not adversely affected by the higher pH and O_2 exceedances of state water quality standards.

[18] NC Wildlife Commission periodically stocked threadfin shad

Table 7. Limnetic forage fish densities (no./ha) in the Catawba-Wateree reservoirs as estimated from Hydroaccoustics sampling from 1993–2003 (Table E3. 1-7, from Duke Energy, 2007).

	Forage fish density, number/hectare											
LAKE	**1993***	**1994***	**1995***	**1996****	**1997****	**1998****	**1999****	**2000****	**2001****	**2002****	**2003****	**MEAN**
JAMES												
Catawba River arm					1,509			7,251				**4,380**
Linville River arm					345			1,429				**887**
Lakewide (area-weighted mean)	**12,120**	**1,454**	**7,708**	**7,683**	**870**			**4,178**				**5,669**
RHODHISS												
Lakewide	**48,195**	**15,227**	**87,465**	**18,351**	**6,510**			**41,834**				**36,264**
HICKORY												
Lakewide	**147,271**	**20,715**	**24,641**	**19,358**	**30,438**			**11,173**				**42,266**
LOOKOUT SHOALS												
Lakewide	**15,492**	**2,055**	**38,909**	**4,448**	**8,655**			**5,377**				**12,489**
NORMAN												
Lakewide (area-weighted mean)	**53,710**	**20,368**	**63,391**	**26,301**	**5,181**	**7,229**	**6,134**	**5,087**	**6,345**		**6,781**	**20,053**
MOUNTAIN ISLAND												
Lakewide	**75,862**	**3,867**	**4,312**	**6,798**	**998**	n/a	**4,413**	**2,530**	**4,554**	**3,752**	**2,366**	**10,945**
WYLIE												
Lakewide (area-weighted mean)	**75,838**	**6,994**	**63,138**	**13,018**	**3,036**			**6,336**				**28,060**
FISHING CREEK												
Lakewide	**9,999**	**12,932**	**37,764**	**1,510**	**3,163**			**32,606**				**16,329**
WATEREE												
Lakewide	**44,490**	**29,632**	**322,324**	**85,007**	**7,402**			**51,102**				**89,993**

Table 8. Number and % Composition of Forage fish species,) in the Catawba-Wateree reservoirs as estimated with Purse Seine sampling from 1993–2003 (Table E3. 1-8, from Duke Energy, 2007)

	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	Mean
James												
# collected	8,578	120	1,320	86	702			4,406				
Gizzard shad	0.12%	100.00%	99.70%	100.00%	81.05%			23.35%				67.37%
Threadfin shad	99.88%	0.00%	0.30%	0.00%	18.95%			76.65%				32.63%
Rhodhiss												
# collected	18,552	1,959	965	460	1,040			23,291				
Gizzard shad	0.92%	100.00%	64.66%	100.00%	72.24%			0.27%				56.35%
Threadfin shad	99.08%	0.00%	35.34%	0.00%	27.76%			99.73%				43.65%
Hickory												
# collected	93,065	435	2,959	1,985	5,903			34,962				
Gizzard shad	0.07%	100.00%	91.92%	99.70%	1.56%			1.97%				49.20%
Threadfin shad	99.93%	0.00%	8.08%	0.30%	98.44%			98.03%				50.80%
Lookout Shoals												
# collected	23,569	1,587	739	699	6,810			1,301				
Gizzard shad	0.01%	100.00%	100.00%	91.13%	0.01%			0.15%				48.55%
Threadfin shad	99.99%	0.00%	0.00%	8.87%	99.99%			99.85%				51.45%
Norman												
# collected	13,063	1,619	4,389	4,465	6,711			4,265				
Gizzard shad	0.00%	0.06%	0.05%	0.00%	0.01%	0.05%	0.26%	0.22%	0.01%	0.00%	0.14%	0.07%
Threadfin shad	100.00%	99.94%	99.95%	100.00%	99.99%	99.95%	99.26%	87.40%	76.47%	74.96%	82.59%	92.77%
Alewife	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.48%	12.37%	23.52%	25.04%	17.27%	7.15%
Mt. Island												
# collected	2,642	583	1,007	1,174	182			2,383				
Gizzard shad	2.27%	0.51%	18.07%	0.43%	0.00%		0.00%	0.00%	0.00%	0.00%	0.00%	2.13%
Threadfin shad	97.73%	99.49%	81.93%	99.57%	100.00%		99.48%	83.28%	89.29%	90.10%	16.92%	85.78%
Alewife	0.00%	0.00%	0.00%	0.00%	0.00%		0.52%	16.72%	10.71%	9.89%	83.09%	12.09%
Wylie												
# collected	125,894	19,026	6,612	4,321	9,842			7,507				
Gizzard shad	0.01%	0.01%	0.00%	0.23%	0.01%		0.04%	0.00%	0.02%	0.00%	0.22%	0.05%
Threadfin shad	99.99%	99.99%	100.00%	99.77%	99.99%		99.96%	100.00%	99.96%	99.99%	99.10%	99.88%
Alewife	0.00%	0.00%	0.00%	0.00%	0.00%		0.00%	0.00%	0.02%	0.01%	0.68%	0.07%
Wateree												
# collected	26,867	350	83,622	52,768	47,767			31,487				
Gizzard shad	0.83%	20.00%	1.63%	10.06%	1.69%			0.06%				5.71%
Threadfin shad	99.17%	80.00%	98.37%	89.94%	98.31%			99.94%				94.29%

5. SUMMARY

In 2000, NCDWQ classified this reservoir as mesotrophic and fully supporting all drinking water supply, aquatic life, and primary and secondary recreational uses, with no fish advisories. During the 1999-2002 low flow years, both Valdese and Lenoir experienced taste and odor problems in their potable water supply and NCDWQ reported high dissolved oxygen above saturation levels, high pH and high chlorophyll levels. However, by 2004, with six of seven water quality parameters identified as lake stressors (percent saturation DO, algae, chlorophyll a, pH, sediment, and taste and odor), NCDWQ reported that Rhodhiss Lake suffers from eutrophication and was impaired in its support of aquatic life. In 2008, the North Carolina 303(d) list was updated to include Rhodhiss Lake for exhibiting high pH values and recommended a basin wide nutrient control program.

The objectives of this report were to:

1. Evaluate the historic-in-lake water quality data compared to NC State Water Quality Standards,
2. Evaluate the historical nutrient loading and export from Lake Rhodhiss, and, to utilize the historic in-lake data from NCDWQ, Duke Energy, and the USGS for lake dynamics, nutrient levels, and biological activity as related to nutrient loading and export, and,
3. Evaluate the historical nutrient concentrations measured in the Rhodhiss Tailrace as a measure of overall reservoir water quality.

Data from 1973 through 2014 was collected by the USEPA, Duke Energy, USGS, and NCDENR and were compiled and collated for this report.

Findings:

1. Since 1973, 10-20% of the surface water pH measurements and 25-45 % of the percent DO saturation values exceeded state water quality standards (pH ≥ 9 and DO_{sat} ≥ 110%).

2. Rhodhiss Lake was characterized by a short retention time (14.5 days on average). With minimum storage capability, relatively high inflows, relatively shallow depths, and a large watershed, Lake Rhodhiss is dynamic and, at most times, inflow driven.

3. Significant inflow to Lake Rhodhiss resulted in advective induced stratification. Even though the temperature profiles did not exhibit a strong thermocline (not expected during high advective flow), a stable water column (minimum vertical mixing) was evident by the vertical dissolved oxygen concentrations and pH gradients.

4. The high surface dissolved oxygen and pH values were a result of pulses of high phytoplankton productivity in the surface waters, and, conversely, low dissolved oxygen and pH values in the deeper water were indicative of decomposition/respiration. Small changes of CO_2, either removed by photosynthesis or added due to decomposition/respiration significantly changed the pH due to the very low buffering capacity (alkalinity) of the water.

5. The high algal production rates were not mirrored by significant increases of algal standing crops as measured by chlorophyll concentrations.

6. The highest median chlorophyll values were observed in the mid-way transition zone, which is a typical reservoir characteristic. However, all lake locations periodically experienced high chlorophyll concentrations.

7. Of the 377 chlorophyll samples collected from 1973-2014, only 9 (2.4%) were greater than the state standard of 40 µg/L.

8. During the period of 1997-2004, point source phosphorus loading to Rhodhiss Lake was 60% of the total load. This percentage was reduced to 43% by 2005-2014.

9. The reduced phosphorus loads were due to a 75% phosphorus reduction from the Valdese WWTP and a 48% reduction from the Lenoir WWTP facility

10. The non-point source phosphorus loading increased 18% between 1997 and 2014. Bridgewater Hydro contributed only 11% of the phosphorus load throughout the years.

11. Rhodhiss Lake released 53% and 55% of the inflowing phosphorus to Lake Hickory from 1997-2004 and 2005-2014, respectively. Even though ≈46% of the inflowing phosphorus was retained in Rhodhiss Lake, internal loading (phosphorus release from the sediment) was not evident.

12. The median seechi disc depths, turbidity and suspended solids trends reflected suspended sediment entered the lake and gradually settled out in the lake as the water progresses downstream in the reservoir.

13. The phosphate discharged from both the Lenoir and Morganton WWTP's were rapidly adsorbed unto particulate material and, as inflow decreased in late summer, the concentration of phosphorus at the Huffman Bridge gradually rose since less dilution water from Bridgewater or the watershed was available in late summer and early fall.

14. With the adsorption of phosphorus on both inorganic and organic particles and subsequent sedimentation as the water slowed in the reservoir, the phosphorus was removed from the upper euphotic zone and accumulated in the deeper depths and sediments.

15. Approximately 20% of the total nitrogen input to the lake originated from the WWTP facilities.

16. The non-point source nitrogen loading increased 20% between 1997 and 2014.

17. Valdese reduced nitrogen input by 48%, the Morganton WWTP increased nitrogen loads 44% between the years 1997 and 2014.

18. Bridgewater Hydro contributed 30% of the nitrogen throughout the years.

19. Rhodhiss Lake released 92% of the inflowing nitrogen to Lake Hickory from 1997-2004. However, during the 2005-2014 period, 7% more nitrogen was released downstream than was added to the lake by all of the point or non-point sources (indicating nitrogen release from the sediment or nitrogen fixation by the phytoplankton within Rhodhiss).

20. Based upon many nutrient loading models, Lake Rhodhiss should be extremely eutrophic (very high chlorophyll concentrations) since its phosphorus loading rate was 5.4 $gm/m^2/yr$ and nitrogen loading was 43.7 $gm/m^2/yr$. These values were 27 times and 15 times higher, respectively, than the permissible levels of nutrient loading described by the models. Clearly, these models do not apply to Lake Rhodhiss and/or the plankton community was limited by other factors.

21. The seasonal molar N:P ratios in the euphotic zone suggest severe summer phosphorus demand as the plankton moves towards the forebay. Little phosphorus from the inflowing rivers or the Valdese WWTP discharge reaches or remains in the surface euphotic zone. Lower N:P ratios in the deeper depths reflect the increased phosphorus from settling phytoplankton, particulate material, or deep Valdese discharge.

22. Based upon the Algal Growth Potential Test reported by the NCDENR, Rhodhiss waters were nitrogen limited. However, during the summer months as the water approaches the forebay, the plankton became severely phosphorus limited forcing the natural phytoplankton to rely on high re-cycling rates of phosphorus to sustain growth and production rates.

23. The autotrophic phytoplankton in Lake Rhodhiss exhibited a diverse assemblage of nearly all taxonomic groups typically found in temperate lakes. The taxonomic diversity as well as the specific population levels (algal densities) was a response to specific requirements for light, temperature, nutrients (macro and micro), buoyancy regulation, competition, productivity, generation times, and predation.

24. The phytoplankton in Lake Rhodhiss exhibited adaptive features to take advantage of the changing characteristics of the lake resulting in various species dominating the phytoplankton in any given year.

25. Nitrogen deficiencies, relative to phosphorus, (low molar N:P ratios) also occurred some years which would trigger potential nitrogen fixing cyanobacteria populations to expand.

26. The size distribution of the Lake Rhodhiss plankton community revealed that most of the algae (≈ 80% of the density) were less than 20 ɥm. Communities dominated by small cells typically exhibited greater productivity per unit algal biomass than larger cells.

27. What cannot be addressed adequately by quarterly sampling of plankton only in the forebay was whether phytoplankton size decreased downstream as a result of predation or settling or physiological changes.

28. During the 1999-2002 low flow years, both Valdese and Lenoir experienced taste and odor problems in their potable water supply. Granite Falls did not report taste and odor problems with their water supply.

29. Under low inflow conditions, the algal populations (presumably a cyanophyta species) appear to have bloomed upstream but dissipated by the time the water reached the forebay.

30. The species found in Lake Rhodhiss known to have caused taste and odor problems in North American drinking water supplies were quite numerous. Most of the taxa were relatively rare in Rhodhiss, but, Oscillatoria and Lyngbya exhibited the highest populations during the 8 year period.

31. Cylindrospermopsis, a known species to cause taste and odor problems, was identified in the phytoplankton samples prior to 2001, but NCDENR reported Cylindrospermopsis in 2012 samples.

32. Forage fish (threadfin and gizzard shad) densities vary tremendously throughout the years, but may reach levels which significantly impact plankton populations through predation.

33. The fish species and densities indicate that Rhodhiss Lake is a very productive fishery. The composition and standing stock of fish was, on the average, higher than most Catawba-Wateree reservoirs.

34. The transfer of phytoplankton production to higher trophic levels (zooplankton and/or fish) contributed to the overall biological production of the Rhodhiss ecosystem.

6. CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

Lake Rhodhiss did experience high nutrient loading, especially phosphorus, but rarely were algal blooms greater than 20,000 units/ml (a mild bloom, as defined by NCDENR). Non-point source loading of suspended sediment aided in the prevention of high densities of algae by (1) restricting light penetration to the upper few meters thereby reducing the euphotic zone, and, (2) adsorbing phosphorus, either derived directly from the watershed or derived from WWTP facilities, unto particulates which, when entering the lake, settled to the bottom effectively reducing phosphorus throughout Lake Rhodhiss and minimized phosphorus loading into Lake Hickory. Additionally, the inflowing water created the advective flow through the reservoir with the effect of minimizing vertical mixing and keeping phosphorus concentrations deeper in the water column reducing phosphorus availability to the phytoplankton in the euphotic zone.

The phosphorus loading reductions from the Valdese and Lenoir WWTP was quickly realized by lowering phosphorus concentrations in the forebay, and especially lower concentrations entering Lake Hickory from the Rhodhiss Hydro. The low molar nitrogen to phosphorus ratio of the inflowing water suggested that Lake Rhodhiss would be slightly nitrogen limiting to the phytoplankton. But, as adsorbed phosphorus and as organic particulates settle to the deeper water and sediments, and reduced loads, phosphorus levels decrease shifting the algal nutrient limitation to phosphorus, rather than nitrogen. This shift in the N:P ratio would discourage nitrogen fixing cyanobacteria and minimize the probability of taste and odor problems observed at the potable water intakes. Continued phosphorus reductions into Rhodhiss would also minimize the chance of further algal blooms.

6.2 Recommendations

- Continue to lower phosphorus loading from the WWTP’s
- Since high pH and high DO levels were indicators of high photosynthetic rates, they should not be used as a measure of high algal population levels. Based on lower phosphorus loading, and very infrequent high chlorophyll levels, Lake Rhodhiss should be removed from the NCDENR 303d list for impaired waters.
- If taste and odor problems are encountered in the future, samples of the water should be taken to identify the organism responsible.
- Sampling at frequent intervals e.g. twice monthly, in the tailrace of the hydro provides an excellent means to track changing water quality in the whole reservoir. Sampling the hydro tailrace is a very cost effective means to track water quality compared to tributary sampling (with associated flows) and in-lake sampling, particularly only surface water. This would be very useful to interpret reservoir-to-reservoir water quality changes.

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